NOVEMBER 2003 FINAL

Storm Water Monitoring &
Data Management

Discharge Characterization Study Report

CTSW-RT-03-065.51.42

California Department of Transportation

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Executive Summary

The California Department of Transportation ("the Department", or "Caltrans") has completed a comprehensive set of studies designed to characterize stormwater runoff from transportation facilities throughout the state of California. This report includes an overview of the Department's stormwater characterization activities; descriptions of the methods used to produce and evaluate the data; the results of the characterization monitoring and data analysis; and conclusions pertinent to management of stormwater runoff from transportation facilities.

OVERVIEW

Since 1998, the California Department of Transportation has conducted monitoring of runoff from representative transportation facilities throughout California. The key objectives of this characterization monitoring include:

1. Achieve compliance with NPDES Permit requirements;
2. Produce data that are scientifically credible and representative of runoff from the Department's facilities;
3. Provide information that can be useful to the Department in designing effective stormwater management strategies.

In May, 1999, the Department was issued its first statewide NPDES stormwater permit. In response to the requirements of this new permit, the Department initiated in 2000 a three-year Statewide Characterization Study. This comprehensive study was designed to systematically characterize representative sites for each of the Department's major transportation facility types.

In addition to runoff quality monitoring, the Department also implemented monitoring programs to characterize runoff sediment/particle quality, as well as litter studies and runoff toxicity studies. These additional studies are not covered by the current report.

The characterization monitoring data presented in this report include both the results of the three-year statewide study, and the results of other studies conducted prior to or in parallel with the statewide study. In all, over 60,000 data points from over 180 monitoring sites were included in the presentation of monitoring results.

The report includes an in-depth statistical analysis of the factors affecting the quality of runoff from transportation facilities. This statistical analysis is focused on the data from the three-year statewide study, as that data set was designed to be representative of transportation facilities throughout the state, and the data collection was performed using consistent monitoring protocols and data management procedures.

METHODS

To provide for consistent, standardized stormwater data collection and reporting, the Department developed a comprehensive set of monitoring protocols and data management tools. These protocols and tools were designed to ensure the scientific validity and representativeness of the data produced by the Department's monitoring programs. The standard protocols are supported and enforced by a comprehensive data management and quality control program implemented by the Department. Together, these measures enhance the value and usefulness of the Department's monitoring programs, and ensure effective use of taxpayer funds.

The Department's monitoring studies have provided broad geographic coverage throughout the State of California (see Figure 1). Facilities monitored by the Department as part of its discharge characterization activities include:

- Highways
- Maintenance stations
- Park and ride lots
- Rest areas
- Toll plazas
- Weigh stations

In addition to the monitoring conducted at representative, fully operational facilities, additional monitoring and special studies were conducted to address specific issues. For example, highway sites in the Tahoe Basin were monitored for snowmelt runoff quality and for rainfall and snowfall precipitation characteristics, in addition to rainfall runoff. Other specialized studies included microbiological (pathogen indicator) studies, construction site runoff studies, and an in-depth, "first flush" highway runoff study.

The standard list of water quality constituents monitored in the Department's runoff characterization studies includes:

- conventional parameters (pH, temperature, TSS, TDS, conductivity, hardness, TOC, and DOC),
- nutrients (nitrate, TKN, orthophosphate-P, and total P), and
- total and dissolved metals (As, Cd, Cr, Cu, Pb, Ni, and Zn).

Oil and grease and selected herbicides were also included for a subset of specific sites. Other constituents were included in earlier (pre-2000) characterization studies, including selected pesticides and other organic compounds, iron, turbidity, and total and fecal coliform.

The scientifically-valid data gained from the Department's runoff characterization activities may be used to design and evaluate existing and potential new BMPs. The information presented in this report also may be used to assist the Department in assessing the effectiveness of the current stormwater management program, and to provide a foundation for long-term management decision-making.

SUMMARY OF FINDINGS

The major findings of this study are summarized below.

Characterization of Runoff Quality

The quality of stormwater runoff was characterized for each transportation facility type through calculation of summary statistics and data distribution parameters. Statistics were calculated using methods appropriate for data sets that include values below detection ("non-detect data"). The data presented in this report are considered to adequately characterize the quality of runoff from the edge of pavement for highways and other transportation facilities operated by the California Department of Transportation.

Relationships Between Runoff Quality and Other Factors

Multiple Linear Regression (MLR) analysis was employed to assess the factors that influence the quality of runoff from transportation facilities. The results indicated that several environmental and site-specific factors have a significant influence on runoff pollutant concentrations. The effects of AADT, total event rainfall, seasonal cumulative rainfall, and antecedent dry period were statistically significant for nearly all of the constituents evaluated, and were very consistent across pollutant categories. The specific effects of the factors evaluated can be summarized as follows:

- Pollutant concentrations in stormwater runoff increase with higher traffic levels. Sites with higher *AADT* have higher concentrations of nearly every pollutant evaluated.
- As *Cumulative Seasonal Precipitation* increases, pollutant concentrations decrease. This is evidence of pollutant "wash-off" during the wet season, as pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. This effect was consistent for all pollutant categories and constituents.
- Longer *Antecedent Dry Periods* result in higher pollutant concentrations in runoff. This factor provides a measure of the "buildup" of pollutants during dry periods between storms.
- As *Total Event Rainfall* increases, pollutant concentrations tend to decrease; *i.e.*, runoff from larger storms tends to be diluted. This phenomenon is consistent with the interpretation that concentrations tend to be highest in the initial portion of the runoff and are diluted as the storm event continues (i.e., it is consistent with a storm event "first flush" effect).
- *Maximum Rainfall Intensity* was highly correlated with *Event Rainfall* and generally had a similar effect, but was less consistent and significant for fewer constituents.
- Larger *Drainage Areas* tended to result in lower concentrations of a few pollutants for highways, but this effect was not consistent for pollutants at other (non-highway) facilities.

- *Impervious Fraction of the Drainage Area* did not have a consistent effect on pollutant concentrations. Higher imperviousness tended to increase concentrations of some pollutants and decrease others. *Impervious Fraction* had the weakest effect of all the factors evaluated.

Event and Seasonal "First Flush" Effects

The results provide conclusive evidence of both intra-event and seasonal "first flush" effects for conventional parameters, trace metals, and nutrients. The first flush effect results in higher concentrations of pollutants in runoff from the initial phases of a storm and during the early part of the storm season.

In California the lengthy dry season leads to an annual build-up of pollutants on surfaces (such as highways), as evidenced by the positive correlation between runoff pollutant concentrations and antecedent dry period. As the wet season progresses, pollutants are progressively washed off, as evidenced by the negative correlation between cumulative seasonal rainfall and runoff pollutant concentrations. Together these phenomena produce what is known as a "seasonal first flush" effect.

The "event first flush" effect recapitulates the build-up/wash-off phenomena on an event basis, as pollutant concentrations tend to be higher in the earlier stages of rainfall/runoff events. Inferential evidence for this effect is provided by the negative correlation between event rainfall and runoff pollutant concentrations. This finding is corroborated by the preliminary results of a Caltrans "First Flush Characterization Study" designed specifically to answer this question.

Comparisons of Runoff from Different Facility Types

Pollutant concentrations were generally highest in runoff from facilities with higher vehicle traffic. Pollutant concentrations in runoff from lower-traffic facilities (maintenance facilities, park-and-ride lots, vehicle inspection facilities, and rest areas) were generally similar to each other and lower than runoff from highways and toll plazas. This pattern was consistent across the categories of conventional constituents, trace metals, and nutrients. The results for facility types confirm the importance of AADT as a predictor of pollutant concentrations in runoff.

Effect of Local Land Use on Runoff Quality

Pollutant concentrations were generally higher in highway runoff from predominantly agricultural and commercial areas. Pollutant concentrations in highway runoff from residential areas, transportation corridors, and open land use areas were generally similar to each other, and lower than agricultural and commercial land uses. These differences were generally consistent for conventional pollutants, trace metals, and nutrients.

Effect of Geographic Regions on Runoff Quality

Although there were some significant differences, geographic region does not appear to have a consistent, predictable effect on runoff quality, and there was no consistent pattern in the runoff quality from different geographic regions. In general, regions with pollutant concentrations that were significantly higher than average or lower than average tended to be represented by relatively few sites with high or low AADT respectively. These results appear to be more reflective of the effect of AADT on runoff quality than a consistent effect of geographic region.

Trends and Annual Variability

Although there was significant annual variability in runoff quality for most constituents and facilities, there were no consistent patterns or trends in the data over the several years studied. Annual variability typically accounted for less than 10% of the overall variability in runoff quality.

Comparisons with Water Quality Objectives

For the purpose of prioritizing constituents for future pilot monitoring, runoff quality data were compared to California Toxics Rule (CTR) objectives (USEPA 2000) and other receiving water quality objectives considered potentially relevant to stormwater runoff quality. A few parameters exceeded these objectives in a majority of runoff samples. It should be noted that the receiving water quality objectives cited are not intended to apply directly to stormwater runoff discharges, and are used here only in the context of establishing priorities for monitoring. It should also be noted that many constituents monitored do not have relevant water quality objectives. The most notable results of comparisons with the most stringent CTR and other relevant water quality objectives are summarized below.

- Copper, lead, and zinc were estimated to exceed the California Toxics Rule (CTR) objectives for dissolved and total fractions in greater than 50% of samples.
- Based on a relatively small number of samples, diazinon was estimated to exceed the California Department of Fish and Game (CDFG) recommended chronic criterion in 79% of stormwater runoff samples, and chlorpyrifos was estimated to exceed the CDFG recommended chronic criterion in 73% of samples. Neither of these pesticides are routinely applied by the Department to highways or other transportation facilities.

Correlations Between Constituents

Correlations between runoff quality parameters were evaluated to identify relationships that are strong enough for one constituent to serve as a monitoring surrogate for another. Significant correlations were considered to support reduction of the list of standard monitoring constituents.

Correlations were generally strongest within pollutant categories, with few strong correlations between constituents in different categories. Within the conventional parameters, the strongest correlations were observed among parameters associated with dissolved minerals (EC, TDS, and chloride), organic carbon (TOC and DOC), and suspended particulate materials (TSS and turbidity). Within the metals category, total concentrations of most metals were highly correlated, but correlations between total and dissolved concentrations were generally lower, even between total and dissolved concentrations of the same metals. Total petroleum hydrocarbons were generally poorly correlated with all other parameters, but did exhibit a strong correlation between the diesel and heavy oil fractions. Nutrients were generally not strongly correlated within the nutrient category or with other categories (with the odd exception of ammonia and dissolved aluminum). Total and fecal coliform bacteria exhibited no significant correlations within or outside the microbiological category.

Monitoring Constituents

As a means of determining the relative importance of specific constituents for continued monitoring, a multi-tiered approach was used to evaluate the Department's stormwater runoff quality data. The constituents monitored were evaluated with respect to frequency of detection and identification of a transportation-related source for the constituent, as well as comparisons to water quality objectives and correlation with other measured parameters, as summarized above.

The following constituents remain high priorities for monitoring, due to their relatively high levels in runoff and their ongoing usefulness in runoff characterization:

- Copper, lead, and zinc
- Aluminum and iron
- Electrical conductivity, TOC, TSS, pH and temperature

The following constituents receive lower priorities for continued monitoring, due to their relatively low concentrations in runoff, their correlations with other parameters, or the lack of an obvious transportation-related source:

- Arsenic, cadmium, chromium, and nickel
- TDS, ammonia, and nitrite
- Diazinon and chlorpyrifos
- Nitrate, TKN, total phosphorous, and dissolved ortho-phosphate
- Semi-volatile organic compounds, including PAHs
- Pathogen indicator bacteria

Percentage of Metals in the Particulate Fraction

A large proportion of the concentrations of most metals are bound to particulate matter in runoff. Based on data from the Statewide Study for metals with data available for both dissolved and total analyses, lead is present in the highest proportion as particulates (86% on average). Cadmium, chromium, and zinc average between 60-70% in the particulate fraction, and arsenic, copper and nickel average between 50-55% as particulates.

CONCLUSIONS

The extensive monitoring performed by the Department over the past several years, and particularly the recently-completed, three-year Statewide Characterization Study, have provided sufficient data with which to characterize the quality of runoff from Caltrans facilities throughout the State of California, in accordance with the approved Characterization Monitoring Plan (Caltrans, 2002, CTSW-RT-02-004).

The primary environmental factors affecting the quality of edge-of-pavement runoff have been identified and quantified, and major patterns of temporal variability (seasonal and intra-storm) have been characterized. The monitoring conducted to date has focused on runoff from paved surfaces.

AADT is the most important site characteristic in predicting highway runoff quality. Although facility type, geographic region and contributing land use were determined to have some statistically significant effects on runoff quality, these effects are less consistent than AADT.

Pollutant build-up and wash-off are evident in the statistical analysis of the highway runoff quality data, providing support for the concepts of seasonal and event first flush effects.

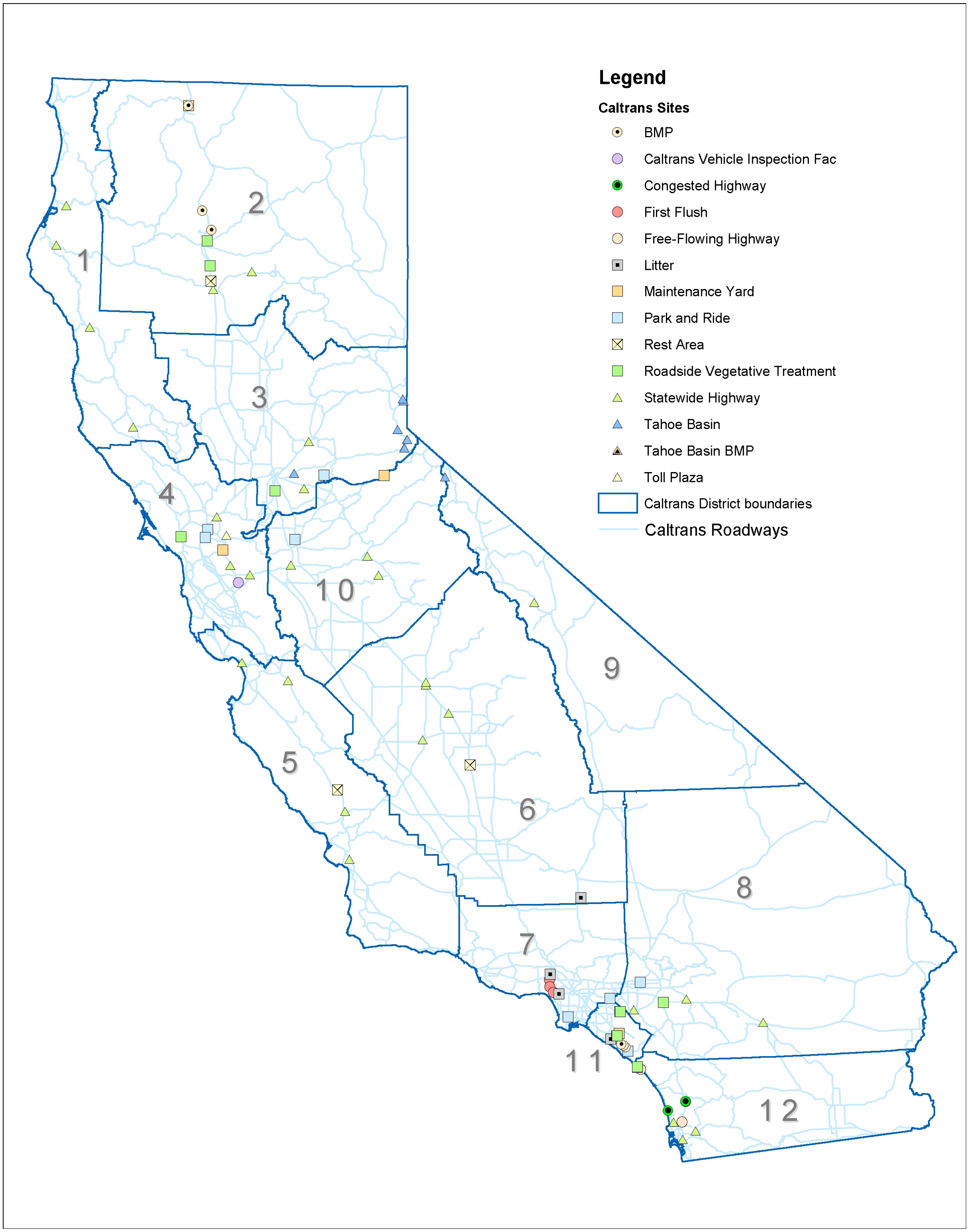

Figure 1 Stormwater Monitoring Sites

SECTION 1 INTRODUCTION

The California Department of Transportation (the Department, or Caltrans) has completed a comprehensive study designed to characterize stormwater discharges from transportation facilities throughout the state of California. This report includes a presentation of the methods used to produce and analyze the data, the results of the various monitoring and research studies, and the conclusions derived from those studies.

CALTRANS STORMWATER CHARACTERIZATION

The California Department of Transportation has taken a multi-faceted approach to stormwater quality monitoring. This approach results in data that can be placed into four categories, encompassing a wide range of stormwater quality issues: Runoff Water Quality, Litter Characterization, Sediment/Particle Quality, and Toxicity Studies (Figure 1-1). This comprehensive approach to stormwater runoff monitoring is further described in "Improving Stormwater Monitoring" (Ruby and Kayhanian 2003). The Department's characterization monitoring studies have been specified annually in the *Characterization Monitoring Plan* (Caltrans, 2002; CTSW-RT-02-004).

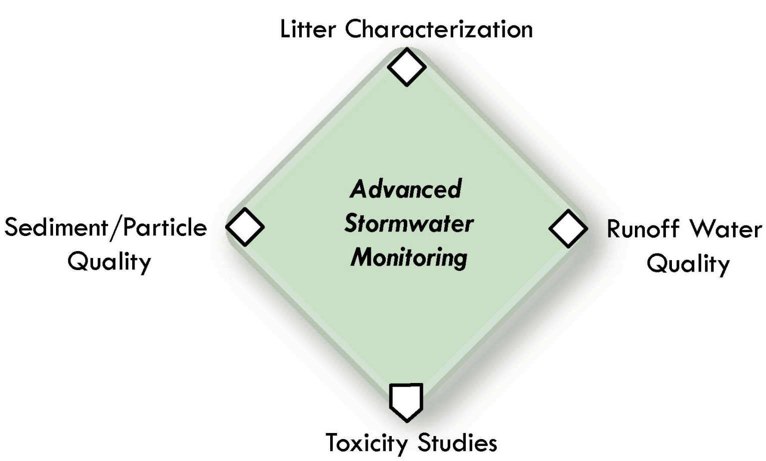

Figure 1-1 Covering the Bases: the Department's Multi-Faceted Approach To Stormwater Quality Monitoring.

Since 1998, the California Department of Transportation has conducted monitoring of runoff from representative transportation facilities throughout California. The key objectives of this characterization monitoring include:

1. Achieve compliance with NPDES Permit requirements;
2. Produce data that are scientifically credible and representative of runoff from the Department's facilities, and can be used to define future monitoring needs;
3. Provide information that can be useful to the Department in designing effective stormwater management strategies.

In May, 1999, the Department was issued its first statewide NPDES stormwater permit. In response to the requirements of this new permit, the Department initiated in 2000 a Statewide Stormwater Runoff Characterization Study. This comprehensive study was designed to systematically characterize, through collection and analysis of representative samples, the quality of stormwater runoff from specific types of transportation facilities. The sites monitored for the Statewide Study were selected to provide representative characterization of the Department's facilities throughout California. Furthermore, this study was conducted to generate sufficient water quality data to satisfy NPDES permit requirements, support research and development needs, provide inputs for load assessment and modeling efforts, provide useful information for watershed planning, and allow for scientifically-sound statistical data quantification.

The data presented and evaluated in this report were gathered principally from The *Caltrans Statewide Stormwater Runoff Characterization Study* (Caltrans, 2003a; CTSW-RT-03-052) . For purposes of general statistical characterization, data from other Department monitoring efforts were also included where appropriate. Stormwater runoff was monitored from over 50 sites in the Statewide Study, representing six different types of facilities: highways, maintenance stations, park and ride lots, rest areas, toll plazas, and vehicle inspection facilities. The study was designed to produce representative data for each facility type nominally over a three-year period, during several storm events annually. The three-year study commenced during the 2000-01 wet season, and was concluded at the end of the 2002-03 wet season (Caltrans, 2003a; CTSW-RT-03-052).

The statewide distribution of monitoring sites covered by this report is illustrated in Figure 1-2.

Monitoring Approach

Data were collected for the statewide characterization study and additional, specialized studies throughout California's geographic and climatic regions, under wide ranges of weather and traffic conditions. Figure 1-3 depicts typical monitoring sites across the state.

Flow can vary significantly throughout a runoff event, and runoff quality is known to vary as well (Stenstrom *et al*. 2001). Flow-proportioned composite samples are therefore considered to be the most representative sampling regimen for runoff monitoring (Kayhanian, 2002). Department monitoring projects generally employ automated monitoring equipment to collect an equal-volume sample (aliquot) for every increment of a pre-set runoff flow volume. Automatic monitoring equipment was used to ensure representative and accurate collection of samples and data (see Section 2 for more detail), including information on flow and rainfall (see photo, Figure 1-4).

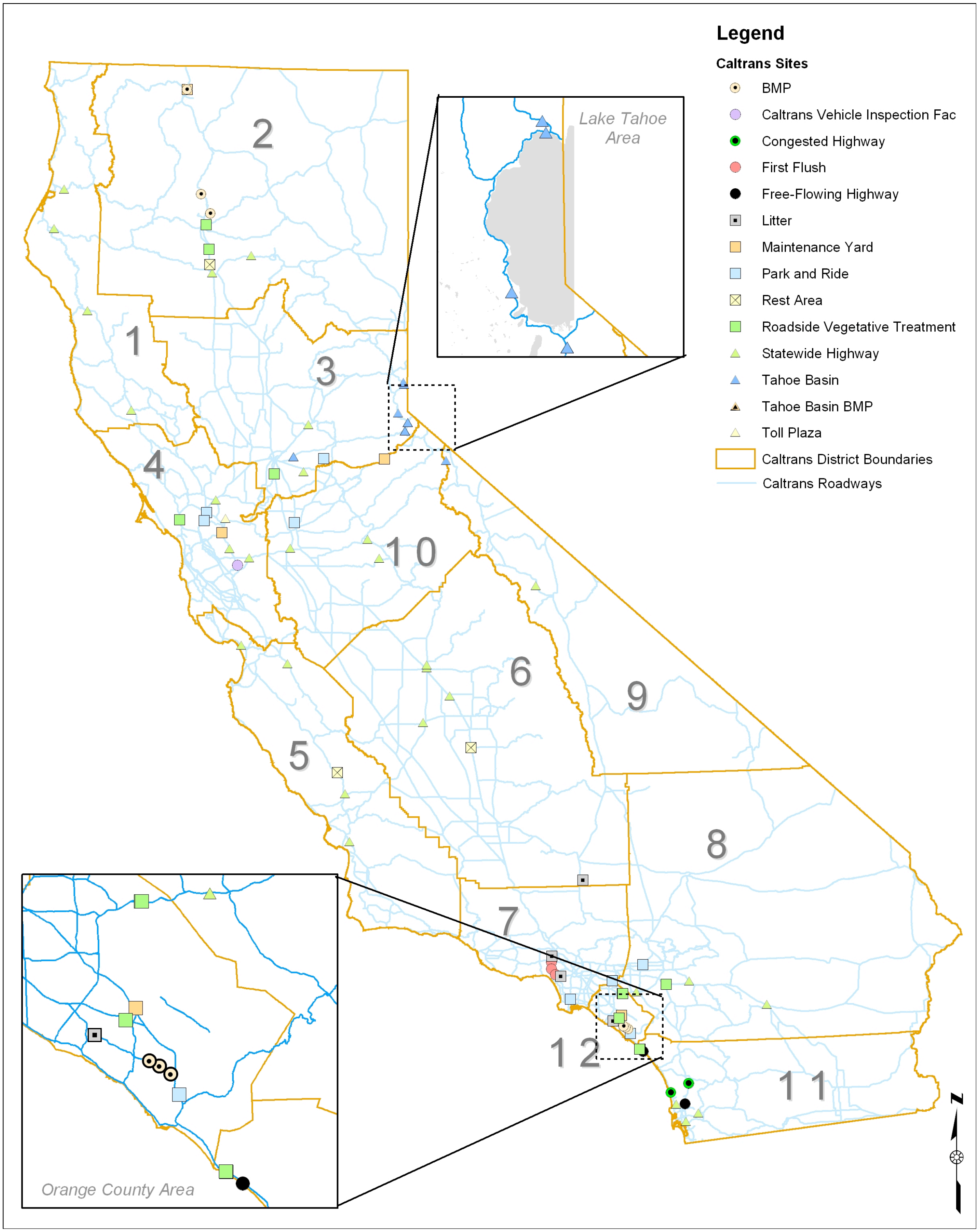

Figure 1-2 Caltrans Monitoring Sites

(a) North Coast Region, District 1

(b) Lake Tahoe, District 3

(c) Orange County Region, District 12

(d) Mojave Desert, District 8

Figure 1-3 (a)-(d). Typical monitoring facilities used in the statewide stormwater runoff characterization study

Figure 1-4 Typical monitoring equipment scenario at enclosed automated monitoring station. Shown are autosampler unit (lower right) and automatic flow meter (top left).

Comprehensive Program Management and Quality Control

To ensure that the Department's monitoring programs produce credible, verifiable and useful data, the Department has developed a comprehensive set of protocols and tools for stormwater monitoring and data management, which are believed to be unique in the field. These include:

- A set of ***planning documents*** that lay out the projects and their objectives;
- A set of detailed ***monitoring protocols guidance manuals***, covering:
    - Water quality (runoff) monitoring,
    - Sediment/particle monitoring,
    - Litter monitoring,
    - Runoff toxicity studies;
- A complete set of ***data reporting protocols*** for the above data categories to ensure consistency in data formatting;
- A comprehensive ***quality assurance/quality control system***;
- Laboratory ***data validation and error checker software***;
- A ***hydrologic software utility*** that converts rainfall, runoff flow, and sampling data into graphical and tabular summaries depicting sample timing and completeness, allowing assessment of compliance with the Department's criteria for composite sample representativeness;
- A ***relational database*** with a user-friendly, geo-referenced interface and menu-driven querying (Figure 1-5); and
- A ***data analysis software tool*** that allows rapid production of summary statistics for selected data sets and includes statistically-based handling of non-detect data (Figure 1-6).

This set of tools and protocols provides monitoring personnel with the means to plan and implement sound monitoring programs, and to verify and interpret the monitoring data. The data may then be used to help improve stormwater management at transportation facilities throughout California.

The software tools developed for the Department's monitoring programs are assembled in an "Electronic Tool Kit" (Caltrans, 2003b; CTSW-OT-02-002).

The monitoring protocols and data reporting protocols developed for the Department's various stormwater monitoring activities are compiled together in the *Comprehensive Guidance Manual for Stormwater Monitoring* (Caltrans. 2003c; CTSW-RT-03-055.36.19).

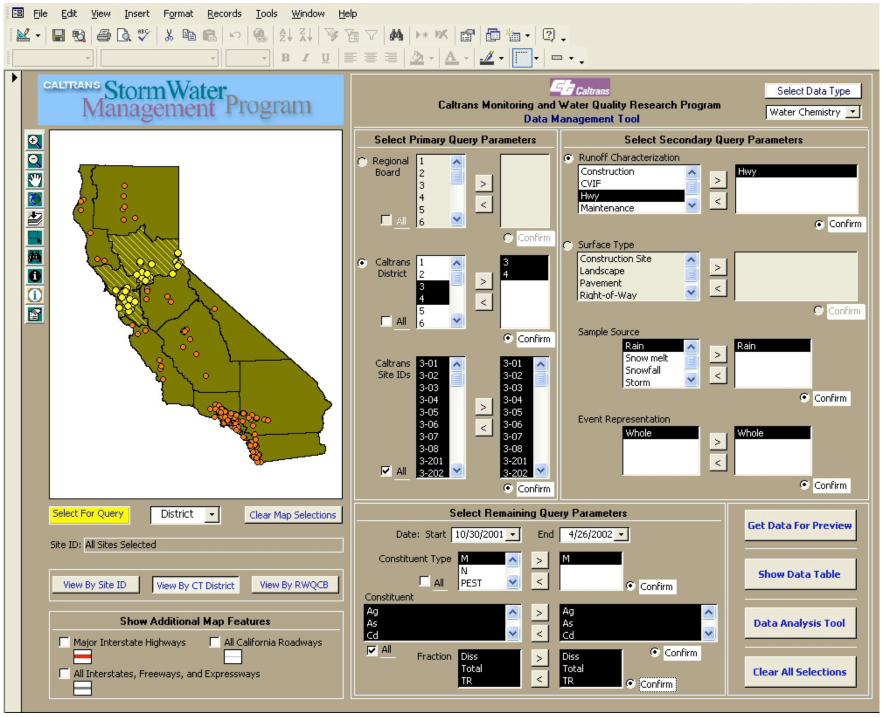

Figure 1-5 Example Screen Shot from Data Management Tool User Interface

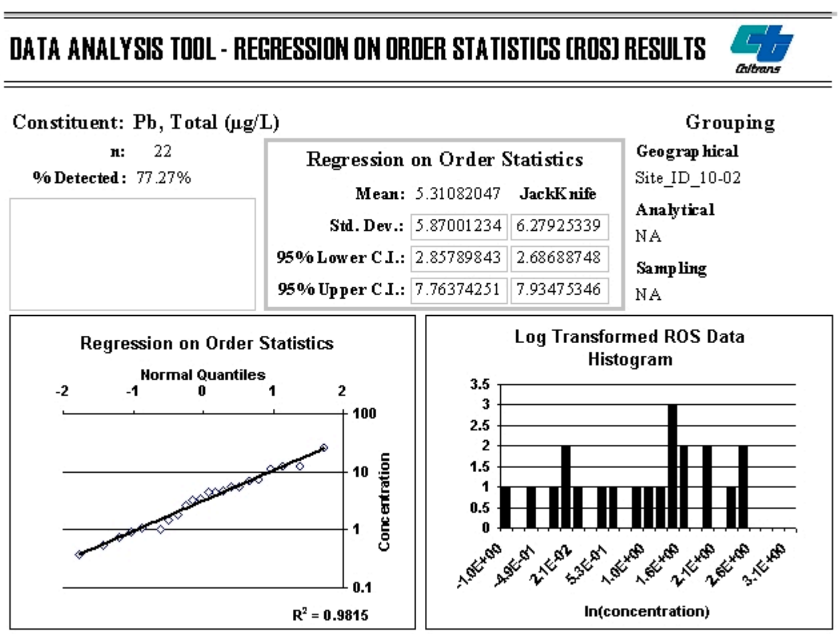

Figure 1-6 Example of Data Analysis Tool Output

CHARACTERIZATION STUDY REPORT OBJECTIVES

This report is designed to address the following objectives, using data generated from the three-year Statewide Stormwater Runoff Characterization Study:

- Quantify the distributional and statistical characteristics of runoff from the different Department facilities.
- Identify relationships between runoff quality and average annual daily traffic (AADT), drainage area, precipitation factors, and antecedent conditions.
- Update Multiple Linear Regression models of stormwater runoff quality produced previously (Kayhanian *et al.*, 2003) using Statewide Study data.
- Identify significant differences in runoff quality from different facility types or from different predominant contributing land uses.
- Determine whether there are significant differences in runoff quality from different geographic regions.
- Determine whether there are significant trends or annual variation in runoff quality.
- Determine whether there are significant seasonal patterns in runoff quality (i.e., a seasonal "first flush" effect).
- Determine whether there are within-storm patterns in runoff quality. Specifically, determine if an intra-event "first flush" effect exists.
- Identify relationships (correlations) between runoff quality parameters. Determine if such relationships can be used to reduce the number of parameters monitored.
- Compare runoff quality to the water quality objectives within the California Toxics Rule and other relevant regulations to prioritize parameters selected for BMP management.

REPORT ORGANIZATION

This report includes:

- an overview of the Department's stormwater monitoring and research program and the objectives of the characterization study report (Section 1);
- descriptions of the methods used to produce and evaluate the characterization monitoring data (Section 2);
- the results of the characterization monitoring and data analysis (Section 3);
- discussion of the results (Section 4); and
- conclusions (Section 5).

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SECTION 2 METHODS

DATA COLLECTION

Data Collection for Stormwater Characterization

Sample Collection

To ensure that the data produced by the Department's various monitoring projects use consistent methods, produce scientifically valid data, and are cost-effective, the Department produced the *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005). The monitoring data presented in this report were produced according to the methods specified in this manuals.

Automated Composite Sampling

Because flow and pollutant concentrations vary throughout runoff events, the Department uses automated monitoring equipment to collect flow-proportioned composite samples. The key elements of the Department's standard automated set-up include an automated composite sampler, flow meter, rain gauge, and programmable data logger/controller. The runoff volume increment is set in advance based on the quantity of precipitation forecast, so that an adequate number of aliquots will be collected to provide sufficient composite sample volume for all planned analyses. The composite sample then represents the full event hydrograph – and accounts for variation in flow and/or runoff quality throughout event. See Figure 2-1 for a schematic representation of the typical monitoring set-up.

Clean Sampling Techniques

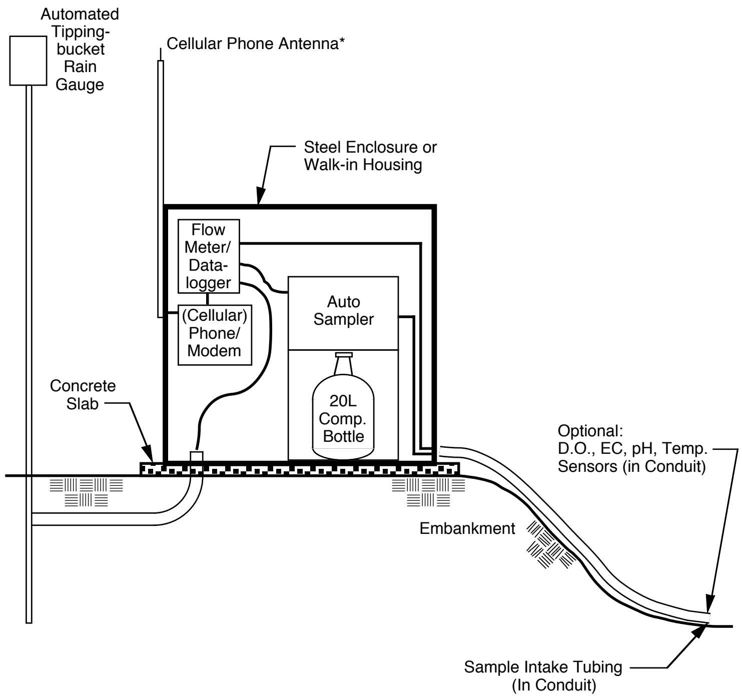
To provide superior quantification for analytical data, the Department's monitoring programs require low-level analytical reporting limits (see Table 2-1) in accordance with the Monitoring Protocols Guidance Manual. In turn, clean sample handling techniques are required to reduce the possibilities of sample contamination. The *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005) contains specific sampling instructions for clean sample handling methods to minimize sample contamination.

Constituents Monitored

Monitoring for the aforementioned studies was conducted in accordance with the *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005). Table 2-1 presents the minimum list of constituents used for the Department's stormwater monitoring projects by pollutant category.

Quality Assurance/Quality Control

The Department's monitoring projects include a comprehensive QA/QC program to ensure that sample contamination is minimized, and to provide data with recordable accuracy and precision. Within each Sampling and Analysis Plan, there is a schedule for the monitoring year listing the events and locations for collection of field blanks, field duplicates, laboratory duplicates, and matrix spike samples.



*Cellular phone module and antenna not needed if land line is available.

Note: 12 volt deep cycle marine batteries (with optional solar charging system) are required if AC power is not available.

Figure 2-1 Schematic representation of the typical monitoring set-up

Table 2-1 Water Quality Parameters Monitored in Stormwater Runoff, 1997 – 2003: Minimum Constituent List for Characterization [(1)]

Constituent	Units	Reporting Limit
Conventional Pollutants		
Conductivity	mmhos/cm	1 [(2)]
Hardness as $CaCO_3$	mg/L	2
pH	pH Units	± 0.1[(2)]
Temperature	°C +/-	± 0.1[(2)]
Total Dissolved Solids	mg/L	1
Total Suspended Solids	mg/L	1
Dissolved Organic Carbon (DOC)	mg/L	1
Total Organic Carbon	mg/L	1
Nutrients		
Nitrate as Nitrogen (NO_3-N)	mg/L	0.1
Total Kjeldahl Nitrogen (TKN)	mg/L	0.1
Total Phosphorous	mg/L	0.03
Dissolved Ortho-Phosphate	mg/L	0.03
Metals (total recoverable and dissolved)		
Arsenic	µg/L	1
Cadmium	µg/L	0.2
Chromium	µg/L	1
Copper	µg/L	1
Lead	µg/L	1
Nickel	µg/L	2
Zinc	µg/L	5
Herbicides [(3)]		
Diuron	µg/L	1
Glyphosate	µg/L	5
Oryzalin	µg/L	1
Oxadiazon	µg/L	0.05
Triclopyr	µg/L	0.1

(1) For analytical methods and other specifications, see Reference appropriate Caltrans document(s).

(2) Report to +/- 0.1 of the nearest standard measurement unit

(3)Analysis for the listed herbicides performed for Caltrans statewide characterization monitoring only.

Composite Sample Representativeness
Two measures are used in the Department's Stormwater Monitoring and Research Program to determine whether a composite sample is adequately representative of the runoff event from which it was collected. Each composite sample consists of a number of individual sample aliquots collected on a flow-proportioned basis throughout the runoff event; the aliquots are then mixed to form a composite sample that can be analyzed by the laboratory. The Department specifies a minimum number of sample aliquots that must be collected for the event, based on the overall rainfall amount. The Department also specifies a minimum "percent capture" for each event, which is essentially defined as the percentage of total event runoff flow during which composite sample collection occurred. These measures are evaluated upon completion of the monitoring event, and a decision on the acceptability of the composite sample representativeness is made prior to laboratory analysis of the samples. The Caltrans Hydrologic Utility (Caltrans, 2003b, CT-OT-02-002; also see description in Ruby and Kayhanian, 2003) is a software tool used by monitoring personnel to assess composite sample representativeness according to the prescribed criteria. This software utility is used to convert flow and sample aliquot data into usable information, and allow assessment of sampling representativeness on site.

Data Management and Validation
The Department's monitoring programs include a comprehensive data management and validation process (including QA/QC evaluation) that is an essential element in providing accurate, reliable, and representative data.

In addition to the Monitoring Protocols Guidance Manual, The Department has established a specific set of Data Reporting Protocols. These data reporting protocols provide detailed specifications for data fields and instructions for content. The protocols help ensure that data from all projects will be reported in consistent format – and that the data records will include sufficient information to permit their full use within the Department's Stormwater Database.

A thorough data quality evaluation is performed following receipt of the laboratory data, in which the results of QA/QC sample analyses are compared to the project's data quality objectives, and suspect data are qualified (flagged) as necessary, following guidelines established by the United States Environmental Protection Agency (EPA) for evaluation of inorganic and organic analyses.

The Department's Automated Data Validation (ADV) software (Amano *et al.*, 2001) is used to enhance the evaluation of the data. This automated program permits quick and efficient evaluation of lab data against data quality objectives and standard measures of data quality, and provides extensive error checking for a standard set of possible analytical or data transcription errors. The resulting electronic data deliverable (EDD) is then ready for final checking prior to entry into the Department's stormwater quality database.

The Hydrologic Utility also serves to standardize calculation of important storm and sampling parameters, such as total flow volume, total event rain, estimated percent capture, and others. In addition, the utility generates a hydrograph and a hyetograph in a standardized format from measured hydrologic data.

The final data validation step involves checking that the electronic data deliverable (EDD) conforms to the Department's Data Reporting Protocols for the specific data type; corrections are made as necessary to provide information for any missing or improperly populated data fields.

Characteristics of the Data Set

Table 2-2 provides an overview of the site characteristics of the data set, including the number of sites and monitoring events by facility type, as well as the range of AADT and catchment area sizes represented.

For the Statewide Runoff Characterization Study, representative sites were selected for each facility type and geographic area, according to pre-specified criteria. Refer to the *Caltrans Statewide Stormwater Runoff Characterization Study* report (Caltrans, 2003; CTSW-RT-03-052) for site selection methods.

An effort was made also to provide representative monitoring during the full range of hydrologic and antecedent conditions typically experienced within the various Caltrans Districts. Table 2-3 provides a summary of the monitoring event characteristics from 1997-2003.

Table 2-2 Summary of Site Characteristics and Events Monitored, 1997 – 2003 Monitoring Programs

			Annual Average Daily Traffic		Catchment Area, hectares	
CalTrans Facility Type	**Number of sites**	**Events Monitored**	**Min**	**Max**	**Min**	**Max**
Construction	21	118	NA	NA	0.04	8.5
Caltrans Vehicle Inspection Facility (CVIF)	2	32	2775	3503	0.97	1.68
Erosion	9	24	48000	13500	0.04	1.17
Highway (Statewide Characterization)	39	684	1800	259000	0.08	5.94
Highway (all other projects)	76	1157	3000	328000	0.03	17.32
Maintenance	17	NA	NA	251000	0.1	5.46
Parking	13	NA	NA	107000	0.06	1.13
Rest Area	3	NA	NA	41500	0.21	3.44
Toll Plaza	2	26	70000	100000	0.28	0.28
Summary for all facilities	*182*	*2626*				

"*NA*" indicates that AADT is *Not Applicable* to Facility type

Table 2-3 Summary of Event Characteristics, 1997 – 2003 Monitoring Events

Event Characteristics	Units	Monitoring Year	Number of Events	Min	Max	Median	Mean	Std. Dev.
Antecedent Dry Period	*days*	1998	253	0.6	290	5	15	36
	days	1999	329	0.7	100	4	10	16
	days	2000	646	0.3	121	8	13	17
	days	2001	565	0.2	202	10	13	17
	days	2002	488	0.4	234	11	17	21
	days	*Total*	*2281*	*0.2*	*290*	*7*	*14*	*21*
Cumulative Seasonal Precipitation	*mm*	1998	249	0	928	166	219	206
	mm	1999	312	0	2323	140	213	247
	mm	2000	579	0	1526	123	169	175
	mm	2001	519	0	1488	122	169	182
	mm	2002	436	0	915	121	166	158
	mm	*Total*	*2095*	*0*	*2323*	*127*	*181*	*191*
Event Rainfall	*mm*	1998	252	2.03	76	11	14	10
	mm	1999	329	0.25	104	16	22	19
	mm	2000	622	0.51	110	16	23	21
	mm	2001	550	0.51	97	11	16	14
	mm	2002	489	2	325	23	36	38
	mm	*Total*	*2242*	*0.25*	*325*	*15*	*23*	*25*
Maximum Intensity	*mm/hour*	1998	178	2.03	107	6	10	14
	mm/hour	1999	297	0.25	122	9	16	19
	mm/hour	2000	618	0.25	113	12	17	14
	mm/hour	2001	549	0.51	79	10	14	13
	mm/hour	2002	488	3	107	16	21	16
	mm/hour	*Total*	*2130*	*0.25*	*122*	*12*	*16*	*15*

STATISTICAL METHODS

Overview of Statistical Approach

The principal statistical methods used to address the objectives of this report consisted of Multiple Linear Regression (MLR), Analysis of Variance (ANOVA), and Analysis of Covariance (ANCOVA). Unless specified, thresholds for statistical significance were set at a confidence level of 95% ($p < 0.05$) for all analyses. MLR methods were used to evaluate the effects of precipitation factors, antecedent conditions, annual average daily traffic (AADT), and contributing drainage area on runoff quality. The MLR results were used in the ANCOVA analyses to evaluate the effects of facility type, land use, and geographic region on runoff quality. ANOVA methods were used to assess the contribution of annual variation to the overall variability of runoff quality. Relationships between pollutants in runoff were evaluated using non-parametric correlation methods. In addition to these analyses, summary statistics were calculated for runoff quality data, and distributions of these data were evaluated for normality prior to additional analyses.

MLR, ANCOVA, and ANOVA analyses were performed using only data from the Department's Statewide discharge characterization studies. This data set was used because the monitoring was more consistent in monitoring approach and methods (than earlier Department monitoring), and was specifically designed to be representative of the Department's facilities throughout the state. This consistent approach and design serves to optimize the consistency and representativeness of the results of the analyses.

The methods used to address specific objectives are summarized in Table 2-4. A summary of the analytical approach is also illustrated in Figure 2-2. Details of the statistical methods used are provided in following text.

Table 2-4 Project Objectives and Statistical Methods Used

Project Objectives	Statistical Methods
Describe distributional and statistical characteristics of runoff	Summary Statistics and frequency distribution plots
Update Multiple Linear Regression models with Statewide characterization studies data	Multiple Linear Regression
Identify relationships between runoff quality and site and environmental characteristics.	Multiple Linear Regression
Evaluate seasonal patterns in runoff quality	Multiple Linear Regression
Evaluate within-storm patterns in runoff quality (i.e., intra-event "first flush" effect)	Multiple Linear Regression
Evaluate differences in runoff quality from facility types and surrounding land uses.	ANCOVA
Evaluate differences in runoff quality from different geographic regions.	ANCOVA
Evaluate annual variation and trends in runoff quality	Non-parametric ANOVA
Evaluate relationships (correlations) between runoff quality parameters	Spearman's Rank Correlation Analysis
Compare runoff quality to water quality objectives and prioritize parameters for BMPs	Estimate percent exceedance from distribution characteristics

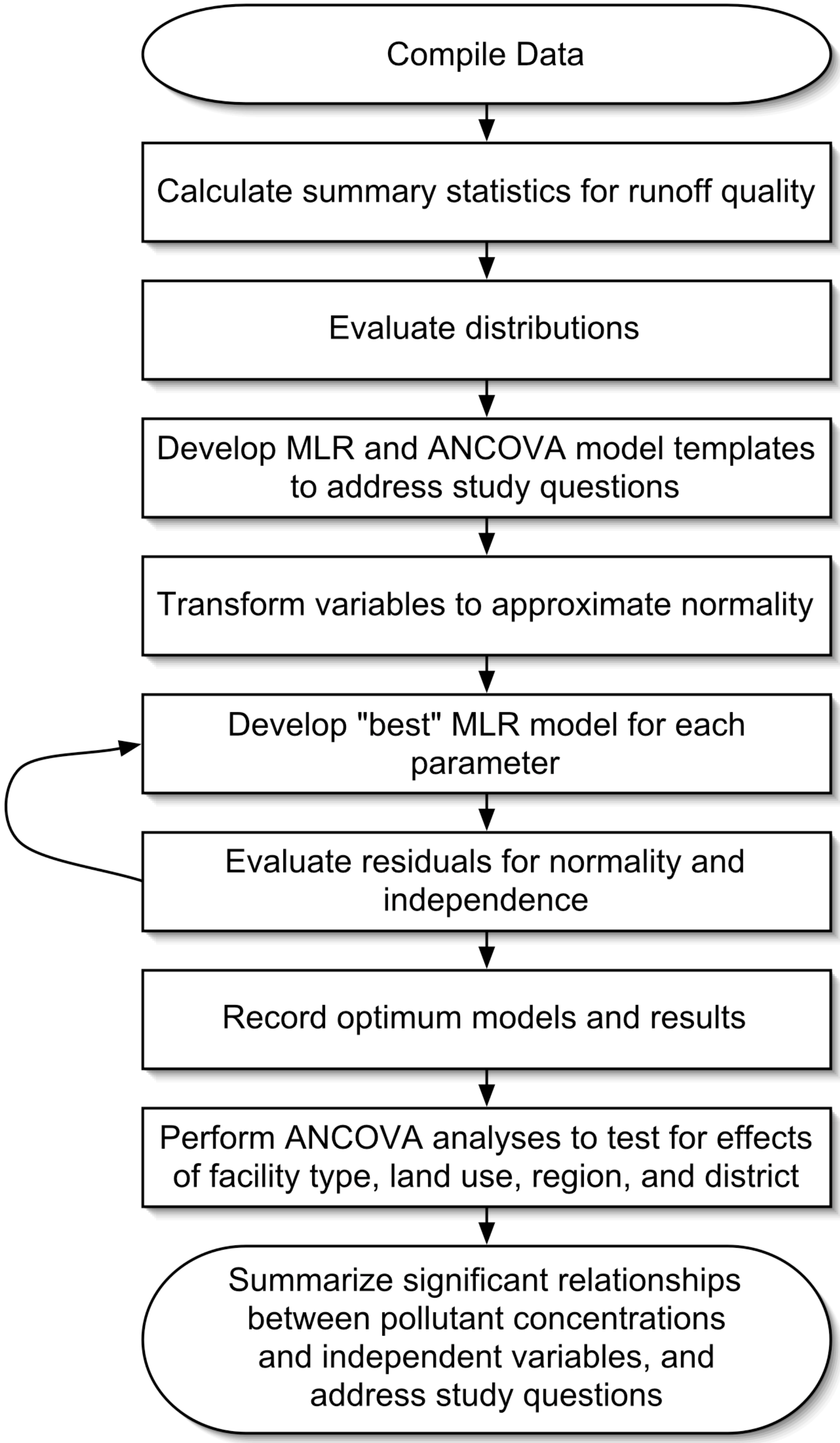


Figure 2-2 Data Evaluation Process

Summary Statistics

Summary statistics and frequency distributions were calculated to address the objectives of describing the distributional and statistical characteristics of stormwater runoff quality from the Department's facilities. Summary statistics were calculated for each constituent for the different facility types contributing the runoff to the sample. Facility types include highways, maintenance stations, Caltrans vehicle inspection facilities (CVIF), parking facilities, rest areas, toll plazas, construction zones, and erosion control sites.

The total number of data, the number and percent of detected data, minimum and maximum detected values, and minimum and maximum detection limits were generated for all data sets and categories. Distribution parameters (arithmetic mean and standard deviation, and 95% confidence limits for the arithmetic mean) were calculated for all categories with a minimum of 30% detected data.

For constituents with data below detection, summary statistics were calculated using the probability regression method described in Helsel and Cohn (1988) and Shumway *et al*. (2002). Use of these methods is important to accurately characterize stormwater runoff data (Kayhanian *et al*., 2002), and this approach is consistent with the methods used previously to analyze the Department's runoff quality (Kayhanian *et al*., 2003).

Summary statistics were also used to estimate the percentage of metals bound to particles in runoff. The percentage particulate fraction was calculated as:
100% x (*average of total metal minus average of dissolved metal) ÷ average of total metal.*

The distributions of runoff quality data for each constituent were evaluated for approximate normality prior to performing additional analyses. Distributions were evaluated using linear and exponential regressions of normal cumulative probability plots of untransformed data. These evaluations were performed using only detected data with probabilities adjusted for data below detection using the method of Helsel and Cohn (1988) and Shumway *et al*. (2002). The regression providing the best fit (as determined by the coefficient of determination or R^2 statistic) was selected as the appropriate starting point for additional analyses, with linear regressions indicating an approximately normal distribution and exponential regressions indicating an approximately log-normal distribution. The distributions of other continuous predictor variables (precipitation factors, antecedent conditions, AADT, and contributing drainage area) were also evaluated by inspection of cumulative probability plots, and were transformed to approximate normality, as follows: natural logarithms (event rainfall, maximum intensity, antecedent dry period, and drainage area), cube-roots (cumulative precipitation), or arcsin-square roots (impervious fraction). Note that these transformations required to satisfy the fundamental statistical assumptions of the analyses and are not necessarily indicative of any underlying physical properties of the predictor variables.

Multiple Linear Regression

Multiple Linear Regression (MLR) analyses were used to address several related objectives of this report:

- Update previously generated MLR models, using only the more consistently-collected Statewide characterization studies data

- Identify relationships between runoff quality and environmental and site characteristics
- Evaluate seasonal patterns in runoff quality
- Evaluate intra-event patterns in runoff quality (i.e., “first flush” effect)

Multiple Linear Regression models were generated using detected data for each constituent. The criteria for selection of constituents for MLR modeling was a minimum of 60% detected data overall, and at least 50 total detected data. Although using only detected data has the potential to bias MLR results by decreasing the magnitude of the model coefficients for the predictor variables, most parameters analyzed had at least 90% detected data and this effect was considered to be negligible for these parameters. There is a greater potential for bias for parameters with between 60% and 90% detected data (total arsenic, total cadmium, dissolved chromium, dissolved nickel, and dissolved orthophosphate), and MLR models for these parameters will provide less accurate predictions of runoff quality, particularly for conditions tending to result in lower pollutant concentrations in runoff. Note that the potential bias in magnitude of MLR coefficients does not effect the sign of the coefficient or invalidate the overall conclusions about the predominant effects of the predictor variables (*e.g.*, whether longer antecedent dry periods or smaller storm events tend to result in higher pollutant concentrations). Potential bias in concentration estimates could be moderated by performing logistic regression analyses in addition to the MLR analyses. Logistic regression models would provide estimates of the expected percent detection of each parameter under specific conditions. Because the conditions of greatest interest to the Department are those that result in the highest pollutant concentrations, the refinement of concentration estimates for conditions expected to result in a high proportion of concentrations below detection was considered not to be warranted for this study.

Methods used for MLR analyses followed standard statistical practice (Zar 1984, Sokal and Rohlf 1981, SPSS 2001). The primary assumptions of MLR analysis (equal variance, normality) were assessed by inspection of residual plots. Problems due to unequal variance and non-normality of residuals were largely avoided by transforming dependent and independent variables to approximate normality prior to analysis. Predictor variables were added to the models using a forward selection procedure that adds predictor variables to the model in the order of highest partial correlation with the dependent variable and retains only statistically significant ($p < 0.05$) variables. Generally, all significant predictor variables were included in the MLR model unless they exhibited symptoms of excessive collinearity or co-dependence in the set of predictors. Independence of predictor variables (the absence of collinearity) was assessed by evaluating several collinearity diagnostic values, including the Tolerance and Variance Inflation Factors (VIF) of each covariate in the model and the Condition Index for the overall model. The Tolerance statistic is interpreted as the proportion of a covariates variance not accounted for by other independent variables in the model. Variables with a low Tolerance statistic (less than 0.7) contribute little additional information to the model. The VIF statistic is the reciprocal of Tolerance and increasing VIF factors indicate increasing collinearity and an unstable estimate of the regression coefficient for that factor. When VIF values were greater than 1.4, at least one predictor variable was excluded from the MLR model to prevent collinearity. The model Condition Index was also used to screen for collinearity problems in the MLR models. Condition indices greater than 15 indicate possible collinearity problems and values greater than 30 indicate serious problems. The MLR models were optimized so that condition indices did not exceed a value of 20.

The validity of the MLR models was assessed in two ways. First, optimized MLR models were compared to models generated previously with the Department's runoff quality data (Kayhanian *et al*., 2003). These qualitative comparisons consisted of assessment of the consistency of the conclusions derived from the two sets of MLR models. Additionally, selected MLR models were evaluated by comparing MLR-predicted values for events and highways sites not used to develop the models (i.e. a new validation dataset) to the concentrations actually measured in runoff. Standard regression methods were used for this validation.

Temporal Trends Analysis

The objective of evaluating temporal trends was addressed using MLR methods (described previously) and non-parametric ANOVA methods. Temporal trends and patterns were assessed at three levels: annual (year-to-year), seasonal, and intra-event. The specific methods used to evaluate each level of temporal variation are as follows:

- The objective of evaluating the annual variability of runoff quality was addressed using non-parametric ANOVA analyses. These were standard ANOVA analyses performed using rank-transformed data for each parameter, with data below detection substituted with a value of zero before being converted to ranks. These analyses were performed separately for each facility type in the data set. The results of these analysis are expressed as the proportion of total variability in runoff quality attributable to annual variation. The statistical threshold for significance was set at the 95% confidence level.

- The effect of the seasonal variation on runoff quality was assessed by evaluating the effect of cumulative seasonal precipitation on runoff quality in the Multiple Linear Regression (MLR) models. Significant negative coefficients for cumulative seasonal precipitation are interpreted to indicate a significant "seasonal first flush" with a tendency for decreasing pollutant concentrations as the wet season progresses.

- The significance of an intra-event first flush was assessed using the MLR results for *Event Rainfall*. A statistically significant negative coefficient for *Event Rainfall* indicates that concentrations tend to decrease as total event rainfall increases. A significant negative coefficient is consistent with the interpretation that concentrations tend to be highest in the initial portion of the runoff and are diluted as the storm event continues (i.e., it is consistent with a storm event first flush effect).

Effects of Facilities, Geographic Region, and Surrounding Land Use

ANCOVA methods were used to address three objectives of this report:

- Evaluate differences in runoff quality from different Department facilities
- Evaluate differences in runoff quality from different geographic regions
- Evaluate differences in runoff quality from different surrounding land uses.

The final "optimized" MLR model was used to generate a new fitted variable calculated as the cumulative effects of the significant predictor variables in each model. This fitted variable was then included as the single covariate in the ANCOVA models used to evaluate the effects of categorical variables (facility, geographic region, and predominant surrounding land use). Interaction effects were evaluated for the cumulative covariate effects (expressed as the MLR-fitted variable) and each categorical variable using standard ANCOVA methods. Interaction effects were retained in the ANCOVA models if they were significant.

This method of ANCOVA analysis does have some drawbacks. Ideally, all of the covariate factors and explanatory factors would be included individually in the ANCOVA models. This method would allow simultaneous evaluation of a broader range of effects and interactions, and theoretically should result in the "best" predictive model. However, an adaptation of standard ANCOVA techniques was required to accommodate the unbalanced dataset, which was not designed to allow a complete and balanced ANCOVA analyses of potential explanatory factors such as geographic region or predominant surrounding land use. There are two specific areas that are compromised by this combined covariate ANCOVA method. The first is a slight inflation of the degrees of freedom used to calculate significance. However, because the degrees of freedom for the models was typically 500 or more, the loss of the few degrees of freedom that would result from including individual covariates has little effect on the overall model significance. More important is the inability to include and evaluate the full range of potential interactions between explanatory variables and individual covariates. Although this may have been partially accomplished by limiting the analyses to only a few specific facilities, georegions, and land uses, such a strategy would have unnecessarily excluded much data of interest to the Department and still resulted in incomplete evaluation of the effects of these factors. The adaptation of ANCOVA methods used for these analyses exchanged some statistical sophistication to allow more complete use of the data to address the Department's primary questions.

When the effects of facility, geographic region, or land use were significant, differences between facilities, regions, and land uses were assessed by comparing the residuals of the MLR models using the method of Least Significant Difference (i.e. without adjustment for multiple comparisons). Differences were generally summarized as significantly greater or less than the overall average for the parameter. The effects of geographic region and surrounding land use were evaluated using only the Statewide characterization studies data for highway runoff because the broad distribution of highway sites provided the most complete assessment of these categorical factors.

Comparisons to Water Quality Objectives

Summary statistics for 1998 – 2002 data were compared to relevant water quality objectives to determine which parameters should be considered highest priority for future BMP implementation or study. Summary statistics for each parameter were compared with California Toxics Rule objectives and relevant limits from several other sources. The sources of other water quality objectives considered were *National Primary Drinking Water Maximum Contaminant Levels* (USEPA, 2002), U.S. EPA *Action Plan for Beaches and Recreational Waters* (USEPA, 1999a), U.S. EPA Aquatic Life Criteria (USEPA, 1999b), California Department of Health Services Drinking Water MCLs (CDHS, 2002), and California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos (Siepman and Finlayson, 2000). In the case of CTR metals objectives that are adjusted for hardness, the objective was based on the lowest observed hardness for the data set in order to provide the most stringent assessment.

These water quality objectives were considered relevant for comparison to stormwater quality because they apply to surface waters which may receive stormwater discharges from highways and other Department facilities. Constituents were prioritized according to their estimated percent exceedance of the most stringent water quality objective. Estimated percent exceedance was calculated based on the distributional statistics calculated for each constituent, using the statistical methods described previously for characterization of runoff quality. The results of these comparisons were then used to rank parameters for monitoring priority, with higher estimated and observed exceedences receiving higher priorities for monitoring. Note that for constituents monitored by the Department, only trace metals and organics have CTR criteria.

Correlations Among Runoff Quality Parameters

Correlations between runoff quality parameters were first evaluated using Spearman's non-parametric rank correlation method, with data below detection set to a value of zero. This evaluation was performed to identify parameter pairs or groups with high correlations and therefore potentially high levels of redundancy for monitoring. The threshold used to identify potentially useful relationships was a Spearman's *rho* value greater than 0.8 and statistically significant at the 95% confidence level. (Spearman's *rho* is the non-parametric equivalent of the parametric Pearson's Product-Moment correlation coefficient, *R*.) After screening with Spearman's non-parametric method, the standard Pearson's Product-Moment correlation coefficient was calculated using only detected data to verify the linearity of the relationship. Statistically significant correlations greater than 0.8 were considered adequately strong for parameters to effectively serve as surrogates for each other. This information was used to prioritize pollutants for continued monitoring.

FACTORS LIMITING ANALYSIS

A number of factors may affect the ability to successfully analyze and interpret stormwater runoff quality data. These include data variability, "representativeness" of sampling methods and data collection, sampling design and pseudoreplication, lack of normality in dependent and predictor variables, collinearity of the predictor variables, and the overall size and quality of the data set.

Data Variability

The high degree of variability in runoff quality data increases the difficulty of demonstrating that significant differences in runoff quality are attributable to facility types, contributing land use, management efforts, or monitoring strategies. By modeling the relationships between runoff quality and precipitation factors through multiple regression analysis, some of the variability inherent in runoff quality data can be explained, thereby increasing the ability to detect effects from other site-specific characteristics. Some of the factors considered to contribute significantly to the variability of stormwater quality data are summarized in Table 2-1.

Sampling Design, Representativeness and Pseudoreplication

Sampling design and data collection methods are critical to the ability to analyze and interpret stormwater quality data correctly. Appropriate design and sampling methods will produce data that are representative of the range of hydrological conditions and runoff characteristics of interest. A good sampling design will also be based on the statistical methods needed to appropriately analyze the data. A poorly designed or biased monitoring program may produce runoff quality data that are not representative of the conditions of interest, or that represent only a limited range of the variability of the data. Even the most rigorous statistical methods can result in incorrect conclusions if based on biased or non-representative data. One of the more common symptoms of an inadequate sampling design is the phenomenon of pseudoreplication, which occurs when a particular treatment or category is represented by only a few sites (or only one site in the extreme case) that are sampled many times. The primary effect of pseudoreplication on statistical analyses is that it results in overestimation of the degrees of freedom used to calculate the error term for the statistical comparison being made (*e.g.* between facility types or land uses), and consequently leads to inflation of the estimated significance of statistical comparisons (Hurlbert, 1984). Data in the Department's Stormwater Quality Database are expected to be representative for the particular monitoring site because the Department's monitoring programs use consistent and well-documented sampling methods that are designed specifically for collection of representative stormwater samples. However, because the Department's monitoring programs were not designed specifically for this type of statistical comparison, pseudoreplication does occur to some degree in the data set used in these analyses. The effects of pseudoreplication manifests primarily in comparisons and conclusions of the effects of categorical variables (*e.g.* facility types) on runoff quality, particularly when one level of a category (*e.g.* rest areas) is represented by only a few sites, and indicates the need for caution in interpreting these comparisons. Problems with pseudoreplication for these analyses were partly controlled by using data from the Statewide characterization studies, which was designed to provide representative data for Department facilities and geographic regions throughout the state. However, although Statewide characterization studies monitoring sites were selected to be representative of "typical" Caltrans facilities, extrapolating results for a facility type with only a few representative sites (or a region with only a few representative highway sites) in the analysis to all such facilities should be done with caution. Note that pseudoreplication has little or no effect on the basic MLR analysis because each combination of event and sampling location is essentially treated as a unique independent observation.

Data Distributions

Normality and equal variance (homoscedasticity) of residuals are two central assumptions of the linear regression analysis and ANCOVA. Although these statistical methods are robust to minor violations, major deviations of these assumptions can reduce the power of these tests to detect significant effects or may lead to inaccurate characterization of effects. These potential limitations were controlled by evaluating data distributions for normality, transforming dependent and independent variables *a priori* to approximate normality if necessary, and finally by inspecting the residuals of the analyses for normality, equal variance, and nonlinearity.

Table 2-5 Factors Contributing to Stormwater Monitoring Data Variability

Category	Specific Factors
Site Specific Factors & Drainage Area Characteristics	• % imperviousness • gradients • vegetation types and coverage • runoff conveyance systems • structural controls • contributing land uses • climate
Meteorological and Storm Event Characteristics	• inter-storm precipitation factors • storm to storm variation • seasonal variation • annual variation
Pollutant Sources	• atmospheric • automotive • construction • building materials • household • commercial/industrial
Human Activities	• population density • traffic patterns • land use • public awareness
Monitoring Factors	• field sampling methods • laboratory and analytical methods

Collinearity

While not a strict requirement, independence of predictor variables (the absence of collinearity) provides an ideal condition for multiple linear regression analysis. Although collinearity does not seriously compromise the predictive value of a multiple regression model, highly correlated predictor variables can make it difficult to interpret the effect of a specific variable (*e.g*. whether it causes an increase or decrease in the dependent variable). As discussed previously, collinearity was assessed using diagnostic statistics for correlations and partial correlations among the predictor variables, and controlled by excluding highly correlated variables from the analysis. In cases where variables were highly correlated, the variable with the largest effect in the models was preferentially retained.

Data Set Quality and Size

Incomplete and censored data sets may also limit the effectiveness of statistical analyses. Incomplete data for storm event or site characteristics can eliminate an event or site from analysis. If these data are randomly missing, then this simply decreases the effective size of the data set and the power of statistical analyses. If the data are systematically missing (*e.g.*, only for storms with more than one inch of rainfall or for a particular type of facility), the data and conclusions based on the data will be biased. This particular type of non-random censoring bias was effectively controlled by the Statewide discharge characterization study's monitoring design, which ensured that runoff quality data were collected for a wide range of environmental and site-specific conditions.

Runoff quality data that are below analytical detection limits are another example of non-randomly censored data. If these data are excluded from the analysis or handled incorrectly, the data set will be biased and may violate the core distributional assumptions of the analyses. Potential biases were limited by restricting the analyses to parameters with low levels of censoring (described previously in this document) to minimize distortion of the underlying distribution characteristics of the data for each runoff quality parameter. While this method still allows for some potential bias of the results, it is preferable to simple substitution methods for censored data which introduce different and less easily predictable biases.

Another factor that can limit the effectiveness of any statistical analyses is a small data set. However, this is not a significant limitation of the Department's Stormwater Quality database. Over 60,000 total runoff quality data records were included in these analyses. In the Statewide characterization studies dataset used for MLR and ANCOVA analyses, total numbers of data points ("*n*") for individual parameters approached 1,000, and for individual parameters at specific facilities *n* ranged from 24 (*Toll Plazas*) to 635 (*Highways*). The large size of the available data set overcomes many of the other limitations by increasing statistical power and overall robustness of the analyses.

SUMMARY STATISTICS FOR WATER QUALITY DATA

The quality of stormwater runoff was characterized primarily through calculation of summary statistics and distributional parameters for runoff from the different facilities. Statistics were calculated using methods appropriate for estimating these distributional parameters for data that include values below detection ("non-detect data"). Summary statistics for Statewide characterization studies data (monitoring years 2000/01-2002/03) are provided in the Tables 3-1 through 3-6. The statistics presented include the number of samples, minimum and maximum detected values, median, mean, and standard deviation. Statistics are presented for conventional parameters, total petroleum hydrocarbons, trace metals, nutrients, pesticides and herbicides, and semi-volatile organic compounds for the following Department facilities:

Facility	Table number	Page reference
Caltrans Vehicle Inspection Facilities	Table 3-1	Page 26
Highways	Table 3-2	Page 27
Maintenance Facilities	Table 3-3	Page 28
Park-And-Ride Facilities	Table 3-4	Page 29
Rest Areas	Table 3-5	Page 30
Toll Plazas	Table 3-6	Page 31

Percentages of total metals present as particulates are summarized in Table 3-7 for all facility types.

Statistics are also provided for the complete data set (monitoring years 1998/99-2002/03) in Appendix A. Note that all runoff quality parameters (i.e., the dependent variables) were approximately lognormally distributed, with the exceptions of pH and temperature, which were approximately normal.

For constituents with at least 30% detected data, plots of annual average water quality with 95% confidence limits are presented in Appendix A for the Department's facilities that were monitored for the Statewide characterization studies, 2000/01-2002/03.

Table 3-1 Summary Statistics for CALTRANS VEHICLE INSPECTION FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	31	2	100%	2.5	67.1	13.3	18.5	15.9
	EC	µS/cm	31	2	100%	10.9	690	82.1	113.3	137.3
	Hardness as CaCO3	mg/L	31	2	100%	5	120	28.6	33.5	22.1
	pH	pH	31	2	100%	6.2	8.15	7.1	7.1	0.4
	TDS	mg/L	31	2	97%	19	470	65.1	84.8	92.1
	Temperature	˚C	16	2	100%	7.7	19.3	12.1	12.5	3.3
	TOC	mg/L	31	2	100%	2.6	68	14.3	20.0	16.9
	TSS	mg/L	31	2	97%	20	200	67.3	83.4	53.0
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	31	2	42%	1	2.1	1.0	1.0	0.4
	As, total	µg/L	31	2	68%	1.2	64	1.3	3.4	16.1
	Cd, dissolved	µg/L	31	2	45%	0.2	0.7	0.16	0.20	0.16
	Cd, total	µg/L	31	2	87%	0.2	1.7	0.43	0.56	0.40
	Cr, dissolved	µg/L	31	2	68%	1.1	5.5	1.4	1.8	1.2
	Cr, total	µg/L	31	2	100%	2.1	21	6.7	8.1	4.8
	Cu, dissolved	µg/L	31	2	100%	2	51	11.0	15.6	13.3
	Cu, total	µg/L	31	2	100%	6.2	96	24.8	33.6	24.1
	Hg, dissolved	ng/L	3	1	0%	ND	ND	IDD	IDD	IDD
	Hg, total	ng/L	4	1	50%	12.5	120	IDD	IDD	IDD
	Ni, dissolved	µg/L	31	2	81%	1	9.9	2.7	3.5	2.4
	Ni, total	µg/L	31	2	100%	2.9	20	7.4	8.4	4.7
	Pb, dissolved	µg/L	31	2	55%	1	14	1.1	2.7	3.9
	Pb, total	µg/L	31	2	100%	1.6	180	10.9	21.9	37.7
	Zn, dissolved	µg/L	31	2	100%	23	380	66.1	88.2	79.1
	Zn, total	µg/L	31	2	100%	66	700	206.0	244.5	151.6
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	31	2	100%	0.15	3.53	0.62	0.89	0.81
	Ortho-P, dissolved	mg/L	30	2	73%	0.046	0.48	0.09	0.13	0.12
	P, total	mg/L	31	2	100%	0.046	0.67	0.23	0.28	0.16
	TKN	mg/L	30	2	87%	0.15	12.3	1.15	2.16	2.72
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	6	1	17%	0.1	0.1	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-2 Summary Statistics for HIGHWAY FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	635	46	100%	1.2	483	13.1	18.7	26.2
	EC	µS/cm	634	46	100%	5	743	72.7	96.1	73.4
	Hardness as CaCO3	mg/L	635	46	99%	2	400	26.9	36.5	34.2
	pH	pH	633	46	100%	4.47	10.1	7.0	7.1	0.7
	TDS	mg/L	635	46	97%	3.7	1800	60.3	87.3	103.7
	Temperature	˚C	183	30	100%	4.7	25.4	12.0	12.5	3.4
	TOC	mg/L	635	46	100%	1.6	530	15.3	21.8	29.2
	TSS	mg/L	634	46	99%	1	2988	59.1	112.7	188.8
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	49	10	29%	5	61	1.44	4.95	11.41
	TPH (Diesel)	mg/L	32	4	97%	0.22	13	2.52	3.72	3.31
	TPH (Gasoline)	mg/L	32	4	0%	ND	ND	ND	IDD	IDD
	TPH (Heavy Oil)	mg/L	20	4	95%	0.12	13	1.40	2.71	3.40
Metals	As, dissolved	µg/L	635	46	40%	0.5	20	0.7	1.0	1.4
	As, total	µg/L	635	46	62%	0.5	70	1.1	2.7	7.9
	Cd, dissolved	µg/L	635	46	42%	0.2	8.4	0.13	0.24	0.54
	Cd, total	µg/L	635	46	76%	0.2	30	0.44	0.73	1.61
	Cr, dissolved	µg/L	635	46	80%	1	23	2.2	3.3	3.3
	Cr, total	µg/L	635	46	97%	1	94	5.8	8.6	9.0
	Cu, dissolved	µg/L	635	46	100%	1.1	130	10.2	14.9	14.4
	Cu, total	µg/L	635	46	100%	1.2	270	21.1	33.5	31.6
	Hg, dissolved	ng/L	19	4	16%	2.5	110	IDD	IDD	IDD
	Hg, total	ng/L	23	4	39%	7.8	160	26.0	36.7	37.9
	Ni, dissolved	µg/L	635	46	79%	1.1	40	3.4	4.9	5.0
	Ni, total	µg/L	635	46	95%	1.1	130	7.7	11.2	13.2
	Pb, dissolved	µg/L	635	46	60%	1	480	1.2	7.6	34.3
	Pb, total	µg/L	635	46	94%	1	2600	12.7	47.8	151.3
	Zn, dissolved	µg/L	635	46	99%	3	1017	40.4	68.8	96.6
	Zn, total	µg/L	635	46	100%	5.5	1680	111.2	187.1	199.8
Micro-biological	Fecal Coliform	MPN/100 mL	32	5	97%	23	6000	362	1132	1621
	Total Coliform	MPN/100 mL	32	5	100%	34	160000	3966	13438	34299
Nutrients	NH3-N	mg/L	8	1	100%	0.33	3.9	0.77	1.08	1.46
	NO3-N	mg/L	634	46	90%	0.011	48	0.60	1.07	2.44
	Ortho-P, dissolved	mg/L	630	46	64%	0.014	2.4	0.06	0.11	0.18
	P, total	mg/L	631	46	89%	0.03	4.69	0.18	0.29	0.39
	TKN	mg/L	626	46	94%	0.1	17.7	1.40	2.06	1.90
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	34	5	21%	0.1	1.33	0.04	0.13	0.29
	Diuron	µg/L	367	30	44%	0.5	220	0.37	4.60	18.24
	Glyphosate	µg/L	541	30	56%	5.1	164	8.88	19.61	26.97
	Oryzalin	µg/L	361	30	16%	0.5	77.8	IDD	IDD	IDD
	Oxadiazon	µg/L	365	30	5%	0.05	0.8	IDD	IDD	IDD
	Triclopyr	µg/L	367	30	2%	0.3	830	IDD	IDD	IDD
Semi-volitile Organics	Acenaphthene	µg/L	32	6	3%	0.25	0.25	IDD	IDD	IDD
	Acenaphthylene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(a)Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(a)Pyrene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(b)Fluoranthene	µg/L	32	6	3%	0.05	0.05	IDD	IDD	IDD
	Benzo(ghi)Perylene	µg/L	32	6	19%	0.05	0.17	IDD	IDD	IDD
	Benzo(k)Fluoranthene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Chrysene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Dibenzo(a,h)Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Fluoranthene	µg/L	32	6	19%	0.05	0.1	IDD	IDD	IDD
	Fluorene	µg/L	32	6	3%	0.06	0.06	IDD	IDD	IDD
	Indeno(1,2,3-c,d)Pyrene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Naphthalene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Phenanthrene	µg/L	32	6	9%	0.05	0.14	IDD	IDD	IDD
	Pyrene	µg/L	32	6	25%	0.06	0.13	0.05	0.05	0.03

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-3 Summary Statistics for MAINTENANCE FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	75	7	100%	1.3	82	11.7	18.2	18.2
	EC	µS/cm	56	7	100%	12	660	49.4	80.9	110.6
	Hardness as CaCO3	mg/L	106	7	96%	2	208	17.4	26.7	28.7
	pH	pH	107	7	100%	3.5	8.5	6.8	6.8	0.6
	TDS	mg/L	106	7	97%	4	536	44.6	68.9	78.1
	Temperature	˚C	17	2	100%	8.5	16.5	12.2	12.5	2.8
	TOC	mg/L	107	7	100%	1.7	128	12.7	20.6	23.0
	TSS	mg/L	106	7	100%	6	420	62.4	96.4	95.0
	Turbidity	NTU	29	3	100%	36	430	122.95	144.83	92.23
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	106	7	82%	0.53	81	2.2	9.5	17.3
	As, total	µg/L	107	7	93%	0.585	91	3.4	12.8	23.1
	Cd, dissolved	µg/L	106	7	49%	0.2	1.2	0.19	0.27	0.22
	Cd, total	µg/L	107	7	84%	0.2	2.7	0.46	0.69	0.63
	Cr, dissolved	µg/L	106	7	53%	1	5.9	1.1	1.4	1.0
	Cr, total	µg/L	107	7	99%	1.01	28	3.9	5.1	4.3
	Cu, dissolved	µg/L	106	7	99%	2.4	100	8.8	14.3	17.6
	Cu, total	µg/L	107	7	100%	3	210	17.3	29.5	37.6
	Hg, dissolved	ng/L	7	1	43%	7.85	77	14.4	27.7	51.4
	Hg, total	ng/L	8	1	75%	14.4	230	41.0	65.4	83.7
	Ni, dissolved	µg/L	106	7	57%	1.6	22	2.37	3.72	4.01
	Ni, total	µg/L	107	7	90%	2.08	51	5.48	7.86	7.68
	Pb, dissolved	µg/L	106	7	44%	1	23	0.74	1.64	2.99
	Pb, total	µg/L	107	7	98%	1	130	11.7	21.3	26.5
	Zn, dissolved	µg/L	107	7	98%	1	130	11.7	21.3	26.5
	Zn, total	µg/L	107	7	100%	26	1500	164.6	245.6	259.3
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	107	7	92%	0.12	8	0.41	0.74	1.13
	Ortho-P, dissolved	mg/L	105	7	55%	0.016	3.12	0.04	0.09	0.40
	P, total	mg/L	106	7	95%	0.031	1	0.16	0.23	0.20
	TKN	mg/L	105	7	92%	0.11	11.5	1.24	1.79	1.72
Pesticide & Herbicides	Chlorpyrifos	µg/L	23	3	0%	ND	ND	IDD	IDD	IDD
	Diazinon	µg/L	33	3	39%	0.016	1.4	0.02	0.12	0.30
	Diuron	µg/L	—		—	—	—	—	—	—
	Glyphosate	µg/L	—		—	—	—	—	—	—
	Oryzalin	µg/L	—		—	—	—	—	—	—
	Oxadiazon	µg/L	—		—	—	—	—	—	—
	Triclopyr	µg/L	—		—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—		—	—	—	—	—	—
	Acenaphthylene	µg/L	—		—	—	—	—	—	—
	Anthracene	µg/L	—		—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—		—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—		—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—		—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—		—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—		—	—	—	—	—	—
	Chrysene	µg/L	—		—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—		—	—	—	—	—	—
	Fluoranthene	µg/L	—		—	—	—	—	—	—
	Fluorene	µg/L	—		—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—		—	—	—	—	—	—
	Naphthalene	µg/L	—		—	—	—	—	—	—
	Phenanthrene	µg/L	—		—	—	—	—	—	—
	Pyrene	µg/L	—		—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-4 Summary Statistics for PARK-AND-RIDE FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	179	10	99%	1.03	278	10.8	18.0	28.6
	EC	µS/cm	179	10	100%	6	420	43.6	63.5	65.8
	Hardness as CaCO3	mg/L	179	10	97%	2	420	16.3	26.6	45.9
	pH	pH	179	10	100%	3.9	9.68	6.7	6.8	0.7
	TDS	mg/L	179	10	96%	6	720	38.1	61.7	78.3
	Temperature	˚C	50	7	100%	7.7	21.8	12.2	12.6	3.4
	TOC	mg/L	179	10	100%	1.3	150	12.2	18.6	20.6
	TSS	mg/L	179	10	99%	2	340	48.3	68.5	59.3
	Turbidity	NTU	2	2	100%	29	36	IDD	IDD	IDD
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	179	10	26%	0.53	3	0.5	0.7	0.6
	As, total	µg/L	179	10	47%	0.52	60	0.8	1.4	5.9
	Cd, dissolved	µg/L	179	10	21%	0.2	0.9	0.08	0.12	0.12
	Cd, total	µg/L	179	10	59%	0.2	2.3	0.21	0.30	0.30
	Cr, dissolved	µg/L	179	10	35%	1	5.1	0.7	1.0	0.9
	Cr, total	µg/L	179	10	90%	1	24	2.7	4.0	4.2
	Cu, dissolved	µg/L	179	10	99%	1.1	70	6.2	8.7	8.8
	Cu, total	µg/L	179	10	100%	1.3	120	12.9	17.1	15.2
	Hg, dissolved	ng/L	10	2	0%	ND	ND	IDD	IDD	IDD
	Hg, total	ng/L	11	2	45%	38.6	230	42.7	57.3	73.6
	Ni, dissolved	µg/L	179	10	57%	1	26	2.0	3.3	3.9
	Ni, total	µg/L	179	10	88%	1.9	28	4.8	6.2	4.8
	Pb, dissolved	µg/L	179	10	34%	1	25	0.5	1.3	2.7
	Pb, total	µg/L	179	10	96%	1	78	5.8	10.3	11.5
	Zn, dissolved	µg/L	179	10	96%	1	78	5.8	10.3	11.5
	Zn, total	µg/L	179	10	100%	8.2	960	103.3	154.3	157.1
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	179	10	93%	0.1	5.49	0.32	0.57	0.83
	Ortho-P, dissolved	mg/L	178	10	69%	0.03	1.01	0.07	0.15	0.19
	P, total	mg/L	179	10	98%	0.03	3.27	0.20	0.33	0.42
	TKN	mg/L	176	10	94%	0.13	13.6	1.52	2.28	2.20
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	20	2	15%	0.6	1.7	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Acenaphthylene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(a)Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(a)Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(b)Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(ghi)Perylene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(k)Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Chrysene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Dibenzo(a,h)Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Fluorene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Indeno(1,2,3-c,d)Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Naphthalene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Phenanthrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-5 Summary Statistics for REST AREAS:
Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	53	3	100%	2.1	239	13.0	19.9	39.6
	EC	µS/cm	53	3	100%	9	809	51.7	78.2	132.0
	Hardness as CaCO3	mg/L	53	3	98%	3	484	18.0	33.0	81.2
	pH	pH	53	3	100%	5.7	7.9	6.8	6.9	0.4
	TDS	mg/L	53	3	100%	4	778	38.0	61.2	130.0
	Temperature	˚C	12	3	100%	5.3	16.3	11.0	11.4	3.2
	TOC	mg/L	53	3	100%	2.5	247	15.0	22.2	40.5
	TSS	mg/L	53	3	98%	7	247	44.2	63.3	54.4
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	53	3	47%	1	20	0.6	1.4	3.3
	As, total	µg/L	53	3	57%	1	58	0.9	3.6	11.4
	Cd, dissolved	µg/L	53	3	17%	0.2	1.4	IDD	IDD	IDD
	Cd, total	µg/L	53	3	58%	0.2	2.8	0.17	0.32	0.53
	Cr, dissolved	µg/L	53	3	62%	1	13	1.2	1.9	2.5
	Cr, total	µg/L	53	3	100%	1	18	3.8	4.8	3.8
	Cu, dissolved	µg/L	53	3	100%	2.7	76	7.6	9.6	12.0
	Cu, total	µg/L	53	3	100%	4.6	89	13.1	16.0	14.2
	Hg, dissolved	ng/L	—	—	—	—	—	—	—	—
	Hg, total	ng/L	—	—	—	—	—	—	—	—
	Ni, dissolved	µg/L	53	3	55%	1.3	35	1.9	3.2	5.8
	Ni, total	µg/L	53	3	92%	1.7	42	4.8	7.3	8.3
	Pb, dissolved	µg/L	53	3	45%	1	8.3	0.7	1.2	1.7
	Pb, total	µg/L	53	3	98%	1.1	32	5.1	7.7	8.0
	Zn, dissolved	µg/L	53	3	100%	12	1500	46.2	82.5	263.7
	Zn, total	µg/L	53	3	100%	21	1800	91.1	142.4	298.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—		—	—	—	—	—	—
	NO3-N	mg/L	53	3	94%	0.2	3.83	0.69	0.96	0.88
	Ortho-P, dissolved	mg/L	52	3	83%	0.056	9.3	0.18	0.44	1.67
	P, total	mg/L	53	3	96%	0.08	2.36	0.32	0.47	0.53
	TKN	mg/L	53	3	98%	0.2	81.2	2.10	4.37	14.04
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	—	—	—	—	—	—	—	—
	Diuron	µg/L	3	1	33%	2.2	2.2	IDD	IDD	IDD
	Glyphosate	µg/L	3	1	33%	7.7	7.7	IDD	IDD	IDD
	Oryzalin	µg/L	3	1	33%	1.7	1.7	IDD	IDD	IDD
	Oxadiazon	µg/L	3	1	0%	ND	ND	IDD	IDD	IDD
	Triclopyr	µg/L	3	1	0%	ND	ND	IDD	IDD	IDD
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-6 Summary Statistics for TOLL PLAZAS: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	24	2	100%	3.8	73	18.9	25.6	19.8
	EC	µS/cm	24	2	100%	9	370	85.8	118.9	100.2
	Hardness as CaCO3	mg/L	24	2	100%	8	120	29.6	37.1	27.7
	pH	pH	24	2	100%	6.3	7.6	6.9	6.9	0.4
	TDS	mg/L	24	2	96%	6	280	51.9	81.5	74.2
	Temperature	˚C	18	2	100%	7.8	16.2	12.0	12.3	3.0
	TOC	mg/L	24	2	100%	4.4	76.7	24.7	31.0	20.3
	TSS	mg/L	24	2	100%	20	313	101.4	123.3	77.4
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	24	2	25%	1	1.8	0.7	0.8	0.4
	As, total	µg/L	24	2	79%	1	4.2	1.3	1.5	0.8
	Cd, dissolved	µg/L	24	2	100%	0.2	1.2	0.37	0.43	0.29
	Cd, total	µg/L	24	2	100%	0.5	2.5	1.04	1.15	0.56
	Cr, dissolved	µg/L	24	2	100%	1.2	11	4.4	5.1	2.5
	Cr, total	µg/L	24	2	100%	2.2	31	10.3	12.5	7.7
	Cu, dissolved	µg/L	24	2	100%	6.7	75	21.8	27.3	20.6
	Cu, total	µg/L	24	2	100%	26	110	55.5	59.6	23.0
	Hg, dissolved	ng/L	4	—	25%	63	63	IDD	IDD	IDD
	Hg, total	ng/L	4	—	25%	200	200	IDD	IDD	IDD
	Ni, dissolved	µg/L	24	2	100%	1	16	4.8	6.0	4.5
	Ni, total	µg/L	24	2	100%	4.8	31	12.3	13.7	6.8
	Pb, dissolved	µg/L	24	2	71%	1.4	19	3.1	5.2	5.2
	Pb, total	µg/L	24	2	100%	11	120	27.1	31.6	24.3
	Zn, dissolved	µg/L	24	2	100%	25	340	98.5	123.7	89.4
	Zn, total	µg/L	24	2	100%	140	650	268.3	292.9	131.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—		—	—	—	—	—	—
	NO3-N	mg/L	24	2	96%	0.16	2.78	0.55	0.84	0.81
	Ortho-P, dissolved	mg/L	23	2	39%	0.03	0.18	0.03	0.05	0.05
	P, total	mg/L	24	2	92%	0.077	0.52	0.23	0.25	0.11
	TKN	mg/L	24	2	100%	0.56	5.52	1.91	2.38	1.59
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	7	1	14%	0.1	0.1	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-7 Percentage of Total Metals Present in the Particulate Fraction

Metal	CVIF	Highway	Maintenance	Park-and-Ride	Rest Areas	Toll Plazas	Facility Average
Arsenic	69%	62%	25%	52%	59%	47%	53%
Cadmium	63%	67%	62%	60%	IDD	63%	63%
Chromium	78%	62%	74%	74%	61%	59%	68%
Copper	54%	55%	52%	49%	40%	54%	51%
Nickel	59%	56%	53%	46%	56%	56%	54%
Lead	88%	84%	92%	87%	84%	84%	86%
Zinc	64%	63%	91%	93%	42%	58%	69%

"IDD" indicates there were insufficient detected data to calculate percent particulate fraction.

EFFECTS OF VARIOUS FACTORS ON RUNOFF QUALITY

Effects of Rainfall Parameters, Antecedent Conditions, AADT and Other Site Characteristics

Multiple Linear Regression Results

The relationships between runoff quality and various environmental and site-specific factors were investigated using Multiple Linear Regression (MLR) analysis of the Statewide characterization studies data set. This analysis included the effects of precipitation factors (event rainfall and maximum rainfall intensity), antecedent conditions (cumulative seasonal precipitation and antecedent dry period), annual average daily traffic (AADT), contributing drainage area and percent impervious area on constituent concentrations in storm runoff from the Department's facilities.

The results of the MLR analyses are presented in Table 3-8 (all monitored facilities) and Table 3-9 (highways only), including relevant model statistics and the specific effects of precipitation factors, antecedent conditions, AADT, and drainage area on the Department's facility runoff quality. A summary of patterns in significant covariate effects is provided in Table 3-10 (all facilities) and Table 3-11 (highways).

Two sets of models were developed for 24 constituents: one set for all facilities combined and excluding AADT, and a second set for highway sites only. Statistically significant coefficients of determination (R^2-values with $p<0.05$) ranged from 0.076–0.524 for highways, and from 0.019–0.415 for all facilities combined. The results of these analyses indicate that all of these factors have statistically significant effects on pollutant concentrations in runoff, and that these effects are generally consistent for most pollutants. The interpretation of dominant (most frequently observed) statistically significant effects of precipitation factors, antecedent conditions, contributing drainage area, and annual average daily traffic (AADT) on runoff quality is summarized below as follows:

- A statistically significant negative coefficient for *Event Rainfall* was observed for nearly all pollutants modeled, indicating that concentrations tend to decrease as total rainfall increases for a specific event. This significant negative coefficient indicates that average pollutant concentrations tend to be higher for smaller rainfall events and lower for larger events; this implies that pollutants tend to become diluted in larger storms. This can only be true if, on average, concentrations tend to be higher in the earlier portion of runoff and lower in the latter portion of runoff. By inference, this result is consistent with the existence of an event first flush effect; i.e., the interpretation that concentrations tend to be highest in the initial portion of runoff events, and are diluted as the storm event continues (i.e., it is consistent with a storm event first flush effect).

- A statistically significant positive coefficient for *Maximum Rainfall Intensity* would indicate that higher rainfall intensities tend to result in greater pollutant concentrations in runoff. A significant negative slope would suggests that higher rainfall intensities tend to have a diluting effect. *Maximum Rainfall Intensity* tended to be highly correlated (R^2-value of approximately 0.3) with *Event Rainfall*, had a consistently smaller effect and was less often significant than *Event Rainfall*, and was therefore eliminated from MLR models to prevent collinearity problems.

- *Antecedent Dry Period* had a statistically significant effect in the MLR models for most constituents, and significant coefficients for this factor were all positive, with the exception of pH. The significant positive slope indicates that longer antecedent dry periods tend to result in higher pollutant concentrations in storm runoff, and is consistent with the “buildup” of pollutants during dry periods.
- The effect of the seasonal first flush (*e.g*. the first significant storm event(s) of a season) was assessed by evaluating the effect of *Cumulative Seasonal Precipitation* on runoff quality. The statistically significant negative slope of the coefficient for *Cumulative Seasonal Precipitation* indicates that pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. *Cumulative Seasonal Precipitation* had a statistically significant effect in the MLR models for every Statewide characterization studies constituent, and significant coefficients for this factor were negative in every case.
- A significant positive slope for *Drainage Area* indicates that sites with larger contributing drainage areas tend to have higher pollutant concentrations in runoff. A significant positive slope indicates that sites with larger contributing drainage areas tend to have lower pollutant concentrations in runoff. *Drainage Area* had a statistically significant effect in four of 24 MLR models for highway sites, and eleven of 24 models for all facilities combined. Significant coefficients for *Drainage Area* were negative for all of the highway models, but for only four of eleven combined facility models. There was no clear pattern for this factor and the most common result for this factor was *not significant*.
- A statistically significant positive slope for *Impervious Fraction* indicates that sites with a higher proportion of impervious area tend to have higher pollutant concentrations in runoff. *Impervious Fraction* had a statistically significant effect in four of 24 MLR models for highway sites, and nine of 24 models for all facilities combined. Significant coefficients were evenly divided between positive and negative for highway models, and were negative for six of nine combined facility models. The most common result for this factor was *not significant*.
- A statistically significant positive slope for *AADT* indicates that higher average annual daily traffic tends to result in higher pollutant concentrations in runoff. *AADT* had a statistically significant effect in the MLR models for nearly every constituent, and significant coefficients for *AADT* were predominantly positive. A significant negative slope was observed for only one constituent (dissolved orthophosphate), suggesting that higher *AADT* tends to result in lower concentrations of this constituent in runoff. This counter-intuitive result may indicate that vehicle traffic is not a significant source of this pollutant and that lower *AADT* may be associated with other sources or conditions responsible for orthophosphate in runoff (*e.g*. agricultural land uses or higher percentages of landscaped areas).

The effects of AADT, event rainfall, cumulative precipitation and antecedent dry period are also illustrated using total recoverable copper reported and MLR-predicted values in Figure 3-1 through Figure 3-4, and the cumulative model is illustrated in Figure 3-5. Total copper was selected for this example because it is one of the best (most accurate) MLR models and best illustrates these effects.

Table 3-8 Effects of Precipitation, Antecedent Conditions, and Drainage Area on Runoff Quality from all Department Facilities: Multiple Linear Regression (MLR) Model Statistics and Coefficients for Whole Storm (EMC) data.

Pollutant Category	Dependent Variable, *X* (Runoff Quality Parameter)	Form of X in Model	*Model Statistics* df	Adjusted Model R-Squared	S.E of Model Estimate	*Model Coefficients* (1) *(intercept and independent variables)* constant (y-Int.)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]
Conventional	DOC	Ln(*X*)	944	0.415	0.654	4.377	(-0.452)	—	0.154	(-0.131)	—	(-0.0033)
	EC	Ln(*X*)	945	0.263	0.729	5.338	(-0.393)	—	0.137	(-0.077)	—	—
	Hardness as CaCO3	Ln(*X*)	987	0.158	0.779	4.490	(-0.267)	—	—	(-0.113)	—	—
	pH	*X*	1001	0.063	0.656	7.118	(-0.061)	—	—	(-0.056)	0.086	0.0052
	TDS	Ln(*X*)	924	0.221	0.785	5.141	(-0.358)	—	0.146	(-0.073)	0.078	—
	Temperature	*X*	283	0.114	3.033	13.115	—	—	0.485	(-0.387)	—	—
	TOC	Ln(*X*)	990	0.119	1.012	5.405	(-0.177)	—	—	(-0.163)	—	—
	TSS	Ln(*X*)	934	0.123	1.007	4.972	(-0.146)	—	0.118	(-0.142)	—	—
Trace Metals	As, total	Ln(*X*)	629	0.019	0.939	1.193	—	—	—	(-0.073)	—	—
	Cd, total	Ln(*X*)	744	0.123	0.690	0.471	(-0.172)	—	—	(-0.100)	0.073	—
	Cr, dissolved	Ln(*X*)	695	0.068	0.660	1.513	(-0.119)	—	—	(-0.056)	(-0.100)	—
	Cr, total	Ln(*X*)	911	0.088	0.818	1.742	(-0.125)	—	0.100	(-0.071)	—	0.0054
	Cu, dissolved	Ln(*X*)	943	0.364	0.708	3.632	(-0.390)	—	0.193	(-0.129)	0.080	—
	Cu, total	Ln(*X*)	1003	0.217	0.892	4.732	(-0.326)	—	—	(-0.174)	—	—
	Ni, dissolved	Ln(*X*)	699	0.263	0.571	2.681	(-0.280)	—	0.069	(-0.100)	(-0.078)	(-0.0030)
	Ni, total	Ln(*X*)	892	0.177	0.679	2.703	(-0.226)	—	0.122	(-0.078)	(-0.051)	—
	Pb, dissolved	Ln(*X*)	535	0.057	1.076	1.790	(-0.204)	—	—	(-0.087)	—	0.0053
	Pb, total	Ln(*X*)	904	0.141	1.289	3.940	(-0.189)	—	0.097	(-0.158)	0.310	—
	Zn, dissolved	Ln(*X*)	938	0.276	0.819	5.545	(-0.369)	—	0.162	(-0.135)	—	(-0.0047)
	Zn, total	Ln(*X*)	943	0.269	0.870	6.108	(-0.298)	—	0.181	(-0.139)	0.192	—
Nutrient	NO3-N	Ln(*X*)	870	0.289	0.791	1.409	(-0.424)	—	0.140	(-0.106)	0.146	(-0.0053)
	Ortho-P, dissolved	Ln(*X*)	619	0.165	0.732	(-1.466)	(-0.218)	—	0.091	(-0.089)	(-0.131)	—
	P, total	Ln(*X*)	867	0.137	0.770	(-0.619)	(-0.188)	—	0.147	(-0.084)	—	(-0.0036)
	TKN	Ln(*X*)	871	0.366	0.676	2.330	(-0.397)	—	0.124	(-0.146)	—	(-0.0042)

Pollutant Category	Dependent Variable, *X* (Runoff Quality Parameter)	*Standardized Model Coefficients* (2) Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]
Conventional	DOC	(-0.459)	—	0.189	(-0.318)	—	(-0.0590)
	EC	(-0.401)	—	0.169	(-0.188)	—	—
	Hardness as CaCO3	(-0.274)	—	—	(-0.273)	—	—
	pH	(-0.079)	—	—	(-0.170)	0.128	0.1200
	TDS	(-0.348)	—	0.172	(-0.170)	0.089	—
	Temperature	—	—	0.133	(-0.275)	—	—
	TOC	(-0.142)	—	—	(-0.308)	—	—
	TSS	(-0.118)	—	0.115	(-0.272)	—	—
Trace Metals	As, total	—	—	—	(-0.143)	—	—
	Cd, total	(-0.200)	—	—	(-0.262)	0.102	—
	Cr, dissolved	(-0.150)	—	—	(-0.166)	(-0.150)	—
	Cr, total	(-0.127)	—	0.123	(-0.171)	—	0.0980
	Cu, dissolved	(-0.380)	—	0.227	(-0.301)	0.092	—
	Cu, total	(-0.281)	—	—	(-0.353)	—	—
	Ni, dissolved	(-0.359)	—	0.107	(-0.309)	(-0.117)	(-0.0730)
	Ni, total	(-0.260)	—	0.170	(-0.212)	(-0.069)	—
	Pb, dissolved	(-0.164)	—	—	(-0.157)	—	0.0780
	Pb, total	(-0.118)	—	0.073	(-0.230)	0.230	—
	Zn, dissolved	(-0.333)	—	0.176	(-0.289)	—	(-0.0750)
	Zn, total	(-0.254)	—	0.187	(-0.281)	0.194	—
Nutrient	NO3-N	(-0.393)	—	0.155	(-0.220)	0.161	(-0.0860)
	Ortho-P, dissolved	(-0.237)	—	0.118	(-0.215)	(-0.175)	—
	P, total	(-0.195)	—	0.183	(-0.199)	—	(-0.0670)
	TKN	(-0.408)	—	0.153	(-0.351)	—	(-0.0750)

Notes: "—" indicates variable is not significant or was excluded from model for collinearity problems. An example model equation is provided for dissolved copper:

$$Ln[Cu, dissolved, \mu g/L] = 3.632 - 0.390(LnEventRainfall) + 0.193(LnAntecedentDryPeriod) - 0.129\left(\sqrt[3]{CumulativePrecip}\right) + 0.060(LnDrainageArea)$$

(1) Unstandardized model coefficients: Positive coefficients indicate a tendency to cause an increase in the pollutant concentration or parameter in runoff. Negative coefficients indicate a tendency to cause decrease in the parameter concentration.

(2) Standardized coefficients allow comparison of the magnitude of the effects among independent variables with different measurement units

Table 3-9 Effects of Precipitation, Antecedent Conditions, Drainage Area, and AADT on Runoff Quality from Highways: Multiple Linear Regression (MLR) Model Statistics and Coefficients for Whole Storm (EMC) data.

			Model Statistics			Model Coefficients (1) (intercept and independent variables)								Standardized Model Coefficients (2)						
Pollutant Category	Dependent Variable, *X* (Runoff Quality Parameter)	Form of X in Model	df	Adjusted Model R-Squared	S.E of Model Estimate	constant (y-Int.)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	AADT*10-6 (vehicles/day)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	AADT*10-6 (vehicles/day)
Conventional	DOC	Ln(*X*)	590	0.410	0.614	4.113	(-0.404)	—	0.123	(-0.129)	—	—	—	(-0.435)	—	0.163	(-0.351)	—	—	—
	EC	Ln(*X*)	581	0.480	0.573	4.680	(-0.316)	—	0.110	(-0.032)	—	—	4.222	(-0.343)	—	0.145	(-0.088)	—	—	0.453
	Hardness as CaCO3	Ln(*X*)	579	0.339	0.656	3.841	(-0.220)	—	0.046	(-0.074)	—	—	3.502	(-0.235)	—	0.060	(-0.199)	—	—	0.370
	pH	*X*	582	0.313	0.587	6.585	—	—	(-0.091)	(-0.032)	—	0.0055	4.406	—	—	(-0.135)	(-0.098)	—	0.1330	0.531
	TDS	Ln(*X*)	572	0.292	0.725	4.731	(-0.309)	—	0.126	(-0.050)	—	—	2.582	(-0.310)	—	0.154	(-0.127)	—	—	0.255
	Temperature	*X*	174	0.096	3.174	14.569	—	—	—	(-0.431)	—	—	—	—	—	—	(-0.318)	—	—	—
	TOC	Ln(*X*)	583	0.144	1.086	5.233	(-0.209)	—	0.129	(-0.154)	—	—	—	(-0.153)	—	0.116	(-0.282)	—	—	—
	TSS	Ln(*X*)	575	0.254	1.015	4.275	(-0.124)	—	0.102	(-0.099)	—	—	4.934	(-0.091)	—	0.091	(-0.182)	—	—	0.358
Trace Metals	As, total	Ln(*X*)	389	0.041	0.777	1.210	—	—	—	(-0.087)	—	—	—	—	—	—	(-0.207)	—	—	—
	Cd, total	Ln(*X*)	472	0.205	0.647	0.084	(-0.149)	—	—	(-0.084)	—	—	2.458	(-0.172)	—	—	(-0.228)	—	—	0.268
	Cr, dissolved	Ln(*X*)	505	0.253	0.601	1.098	(-0.109)	—	—	(-0.046)	(-0.246)	—	3.070	(-0.135)	—	—	(-0.136)	(-0.362)	—	0.373
	Cr, total	Ln(*X*)	565	0.240	0.737	1.618	(-0.099)	—	0.106	(-0.055)	(-0.234)	—	3.508	(-0.101)	—	0.131	(-0.139)	(-0.282)	—	0.353
	Cu, dissolved	Ln(*X*)	581	0.508	0.615	2.919	(-0.290)	—	0.185	(-0.102)	—	—	3.679	(-0.286)	—	0.222	(-0.254)	—	—	0.357
	Cu, total	Ln(*X*)	582	0.524	0.722	2.900	(-0.161)	—	0.163	(-0.079)	—	—	6.823	(-0.133)	—	0.164	(-0.165)	—	—	0.555
	Ni, dissolved	Ln(*X*)	474	0.270	0.569	2.731	(-0.270)	—	0.068	(-0.107)	(-0.094)	(-0.0029)	—	(-0.342)	—	0.105	(-0.337)	(-0.142)	(-0.0790)	—
	Ni, total	Ln(*X*)	557	0.224	0.673	2.511	(-0.196)	—	0.141	(-0.075)	(-0.155)	—	1.013	(-0.219)	—	0.193	(-0.208)	(-0.207)	—	0.113
	Pb, dissolved	Ln(*X*)	376	0.076	1.148	2.042	(-0.248)	—	—	(-0.101)	—	0.0065	—	(-0.187)	—	—	(-0.173)	—	0.0950	—
	Pb, total	Ln(*X*)	586	0.364	1.183	2.272	—	—	—	(-0.102)	—	—	9.650	—	—	—	(-0.144)	—	—	0.545
	Zn, dissolved	Ln(*X*)	577	0.316	0.794	4.740	(-0.343)	—	0.164	(-0.112)	—	—	1.676	(-0.308)	—	0.180	(-0.253)	—	—	0.149
	Zn, total	Ln(*X*)	579	0.509	0.757	4.827	(-0.227)	—	0.143	(-0.084)	—	—	6.747	(-0.181)	—	0.139	(-0.169)	—	—	0.532
Nutrient	NO3-N	Ln(*X*)	529	0.371	0.735	1.299	(-0.417)	—	0.092	(-0.090)	—	(-0.0072)	2.870	(-0.387)	—	0.103	(-0.197)	—	(-0.1340)	0.260
	Ortho-P, dissolved	Ln(*X*)	382	0.149	0.694	(-1.160)	(-0.240)	—	0.084	(-0.077)	—	—	(-1.927)	(-0.269)	—	0.117	(-0.209)	—	—	(-0.214)
	P, total	Ln(*X*)	520	0.102	0.776	(-1.212)	(-0.143)	—	0.128	(-0.051)	—	—	0.900	(-0.148)	—	0.163	(-0.128)	—	—	0.094
	TKN	Ln(*X*)	537	0.385	0.656	1.689	(-0.343)	—	0.102	(-0.128)	—	—	1.535	(-0.355)	—	0.128	(-0.331)	—	—	0.155

Notes: "—" indicates variable is not significant or was excluded from model for collinearity problems. An example model equation is provided for dissolved copper:

$$Ln[Cu, dissolved, \mu g/L] = 2.919 - 0.290(LnEventRainfall) + 0.185(LnAntecedentDryPeriod) - 0.102\left(\sqrt[3]{CumulativePrecip}\right) + 3.679\left(AADT \bullet 10^{-6}\right)$$

(1) Unstandardized model coefficients: Positive coefficients indicate a tendency to cause an increase in the pollutant concentration or parameter in runoff. Negative coefficients indicate a tendency to cause decrease in the parameter concentration.

(2) Standardized coefficients allow comparison of the magnitude of the effects among independent variables with different measurement units

Table 3-10 Summary of Significant Covariate Effects for Multiple Linear Regression Models of Runoff Quality from all Department Facilities.

Covariate Factor (predictor variable form)	Dominant effect on pollutant concentrations[(1)]	Ratio of models exhibiting significant dominant effect[(2)]	Exceptions[(3)]	Comments
Event Rainfall (LnX)	Concentrations decrease with higher total event rainfall.	22 of 22 models had a significant negative coefficient	*Positive* : none; *Not significant* : As-tot, temperature	Very consistent predictor. Same pattern for all models.
Maximum Rainfall Intensity (LnX)	Not included in any models	Not included in any models	None (excluded for collinearity problems)	*Not significant* is the most common result. Although significant for some parameters, maximum intensity is highly correlated with event rainfall (R = 0.54). Generally appears not to be a good predictor variable due to collinearity problems.
Antecedent Dry Period (LnX)	Concentrations increase with longer antecedent dry period	16 of 16 models had a significant positive coefficient	*Negative* : none *Not significant* : hardness, pH, TOC, As-tot, Cd-tot, Cr-dis, Cu-tot, Pb-dis	Very consistent predictor. Same pattern for all models.
Seasonal Cumulative Precipitation (Cube Root of X)	Concentrations decrease as cumulative rainfall increases	24 of 24 models had a significant negative coefficient	*Positive* : none *Not significant* : none	Most consistent predictor. Significant for all paramters and same pattern for all models.
Drainage Area (LnX)	No consistent dominant effect	7 of 11 models had a significant negative coefficient	*Negative:* Cr-dis, Ni, dis, Ni-tot, Orthophosphate	Negative for Cr-dis, Cr-tot, Ni-dis, and Ni-tot, but *not significant* is the most common result. Appears to be a poor predictor overall.
Impervious Fraction (ArcSin-SquareRoot of X)	Concentrations decrease as imperviousness increases	6 of 9 models had a significant negative coefficient	*Positive:* pH, Cr-tot, Pb-dis	*Not significant* is the most common result. Effect is small compared to other factors. Appears to be a poor predictor.

(1) Summarized for MLR models including only Statewide characterization studies whole storm data. "Dominant Effect" is the most frequently observed sign of significant coefficients for the factor in MLR models. Concentrations are said to increase if most coefficients are positive, and to decrease if most coefficients are negative. In all cases, the relationship between covariate and dependent variables (after transforming to approximate normality) is approximately linear.

(2) Threshold of statistical significance is $p<0.05$.

(3) Constituents for which the predictor had a significant effect opposite to the dominant effect for the predictor.

Table 3-11 Summary of Significant Covariate Effects for Multiple Linear Regression Models of Highway Runoff Quality.

Covariate Factor (predictor variable form)	Dominant effect on pollutant concentrations(1)	Ratio of models exhibiting significant dominant effect(2)	Exceptions(3)	Comments
Event Rainfall (LnX)	Concentrations decrease with higher total event rainfall.	22 of 22 models had a significant negative coefficient	*Positive* : none; *Not significant* : pH, temperature, As-tot, Pb-tot	Very consistent predictor. Same pattern for all models.
Maximum Rainfall Intensity (LnX)	Not included in any models	Not included in any models	None (excluded for collinearity problems)	*Not significant* is the most common result. Although significant for some parameters, maximum intensity is highly correlated with event rainfal (R = 0.54). Generally appears not to be a good predictor variable due to collinearity problems.
Antecedent Dry Period (LnX)	Concentrations increase with longer antecedent dry period	17 of 18 models had a significant positive coefficient	*Negative* : pH *Not significant* : temperature, As-tot, Cd-tot, Cr-dis, Pb-dis, Pb-tot	Very consistent predictor. Same pattern for nearly all models.
Seasonal Cumulative Precipitation (cube root of X)	Concentrations decrease as cumulative rainfall increases	24 of 24 models had a significant negative coefficient	*Positive* : none *Not significant* : none	Most consistent predictor. Same pattern for all models.
Drainage Area (LnX)	Concentrations are lower for larger drainage areas	4 of 4 models had a significant negative coefficient	*Positive* : none	Negative for Cr-dis, Cr-tot, Ni-dis, and Ni-tot, but *not significant* is the most common result. Appears to be a poor predictor overall.
Impervious Fraction (ArcSin-SquareRoot of X)	No consistent dominant effect	2 of 4 models had a significant positive coefficient	No dominant pattern.	*Not significant* is the most common result. Effect is small compared to other factors. Appears to be a poor predictor.
AADT ($AADTx10^{-6}$)	Concentrations are higher for sites with higher traffic	17 of 18 models had a significant positive coefficient	*Negative* : Orthophosphate *Not significant* : DOC, TOC, temperature, As-tot, Ni-dis, Pb-dis.	Very consistent predictor. Same pattern for nearly all models.

(1) Summarized for MLR models including only Statewide characterization studies whole storm data for highways. "Dominant Effect" is the most frequently observed sign of significant coefficients for the factor in MLR models. Concentrations are said to increase if most coefficients are positive, and to decrease if most coefficients are negative. In all cases, the relationship between covariate and dependent variables (after transforming to approximate normality) is approximately linear.

(2) Threshold of statistical significance is $p<0.05$.

(3) Constituents for which the predictor had a significant effect opposite to the dominant effect for the predictor.

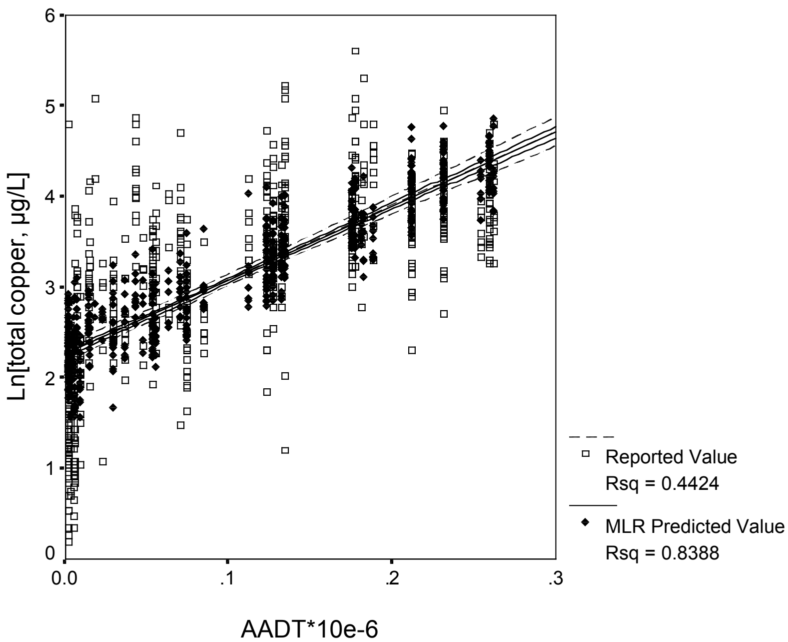


Figure 3-1 Effect of AADT on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified AADT.

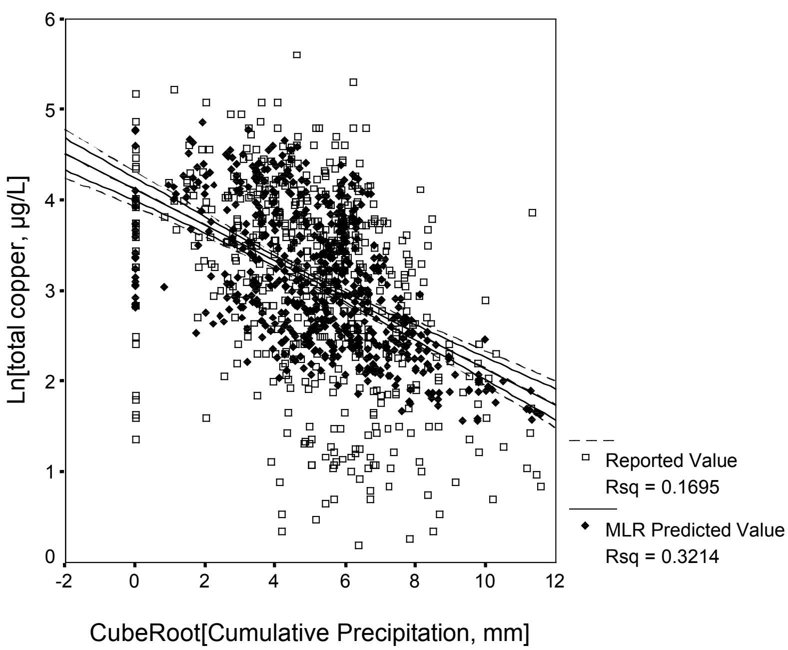


Figure 3-2 Effect of cumulative precipitation on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified cumulative seasonal precipitation.

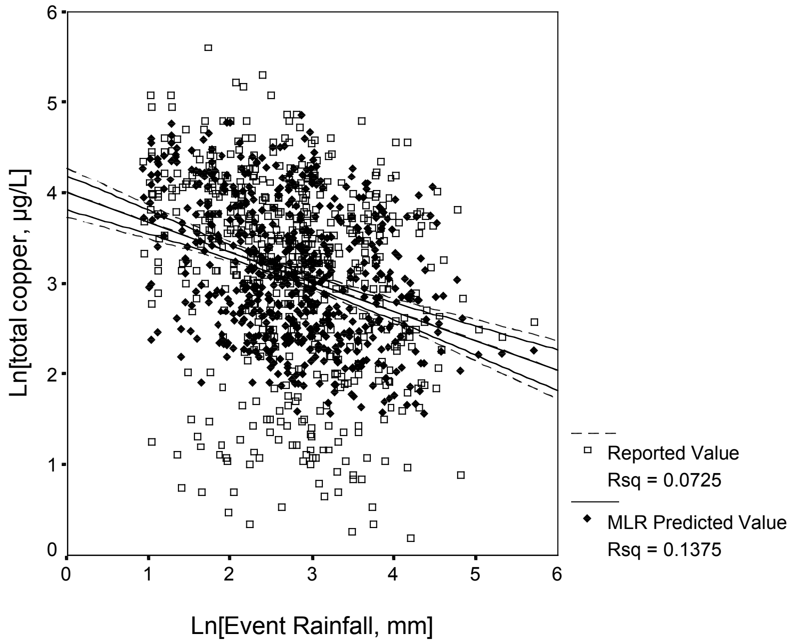


Figure 3-3 Effect of event rainfall on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified event rainfall.

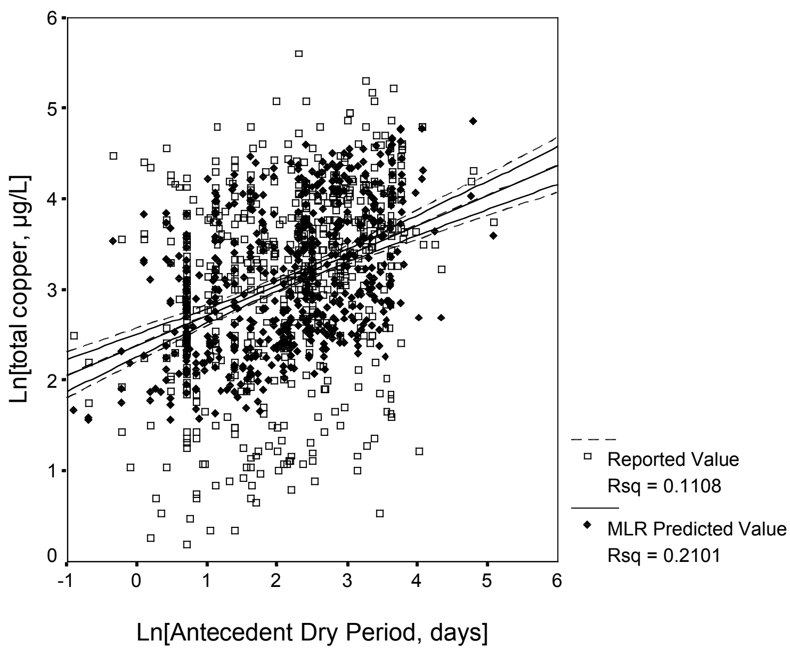


Figure 3-4 Effect of antecedent dry period on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified antecedent dry period.

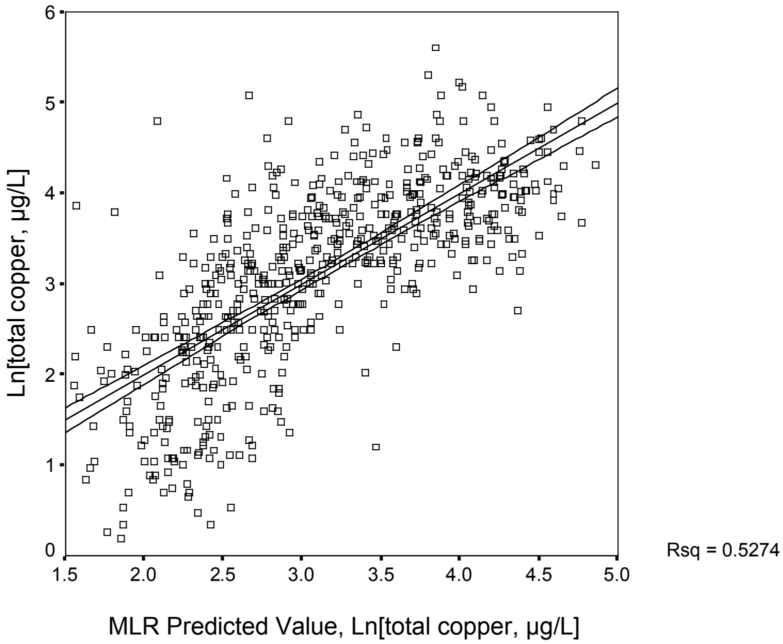


Figure 3-5 MLR model for total copper.
Regression fit lines illustrate mean and 95% confidence interval for mean reported Ln(total copper).

Model Validation
Although not a specific objective of this study, several of the best MLR models were validated using data not included in the dataset used to develop the MLR models. The MLR models for DOC, total copper, total zinc, and nitrate were used to predict concentrations of these pollutants for highway sites and storm events that were not part of the Statewide characterization studies dataset. These parameters were selected as representative models in each pollutant category. These predicted concentrations were compared to actual reported concentrations using standard linear regression analysis. The results of these comparisons are summarized in Table 3-12, and illustrated in Figure 3-6 through Figure 3-9.

The purpose of this validation exercise was to assess how well some of the best models were able to predict pollutant concentrations for new highway sites and storm events. Based on inspection of the regression plots, there was no apparent systematic bias in the predicted values and the range and distribution of the predicted values agreed well with the validation data. Note that the range of predicted values is expected to be smaller than that of the validation data set, because they are model predictions without the inherent variability of actual environmental data. The Coefficients of determination (R^2 values) for the MLR models developed with Statewide characterization studies data were compared with R^2 values for the regressions of validation data on MLR-predicted values for each parameter. The R^2 values for the regression of new data on MLR-predicted concentrations are similar to the R^2 values for the original MLR models, indicating that the overall fit of the validation data was similar to the original data used to develop the models. The slopes of the regressions were also evaluated for potential bias in MLR-predicted values. The slopes of the DOC and total zinc validation regressions were significantly different from one, indicating that models that included the validation data would differ slightly from the MLR models developed for this study. The slopes for the total copper and nitrate regressions were not significantly different from one at the 95% confidence level, indicating that models that included the validation data would not be significantly different from the current MLR models for these parameters. If the regressions of validation and predicted values were forced through zero (i.e., if the intercept was assumed to be zero), the slopes for all four validation regressions were not significantly different from one. Overall, these results indicate that the MLR-models for these parameters provide reasonable and realistic estimates of pollutant concentrations in runoff, and validates the process used to develop these models.

Table 3-12 Results of comparisons of MLR-predicted values to validation data

Model	Coefficients			95% Confidence Interval		Validation R^2	Original MLR R^2
	B	Std. Error	p-value	Lower Bound	Upper Bound		
Ln[DOC]							
Intercept	-.550	.148	.0002	.-.840	-.260		
MLR predicted Ln[DOC]	1.215	.059	<.0001	1.100	1.331	.504	.410
Ln[Total Copper]							
Intercept	.107	.127	.3995	-.142	.356		
MLR predicted Ln[total copper]	.944	.037	<.0001	.871	1.017	.480	.524
Ln[Total Zinc]							
Intercept	.722	.192	.0002	.344	1.099		
MLR predicted Ln[total zinc]	.829	.038	<.0001	.755	.904	.405	.509
Ln[NO_3-N]							
Intercept	.005	.029	.0789	-.006	.109		
MLR predicted Ln[total zinc]	.939	.046	<.0001	.849	1.029	.394	.371

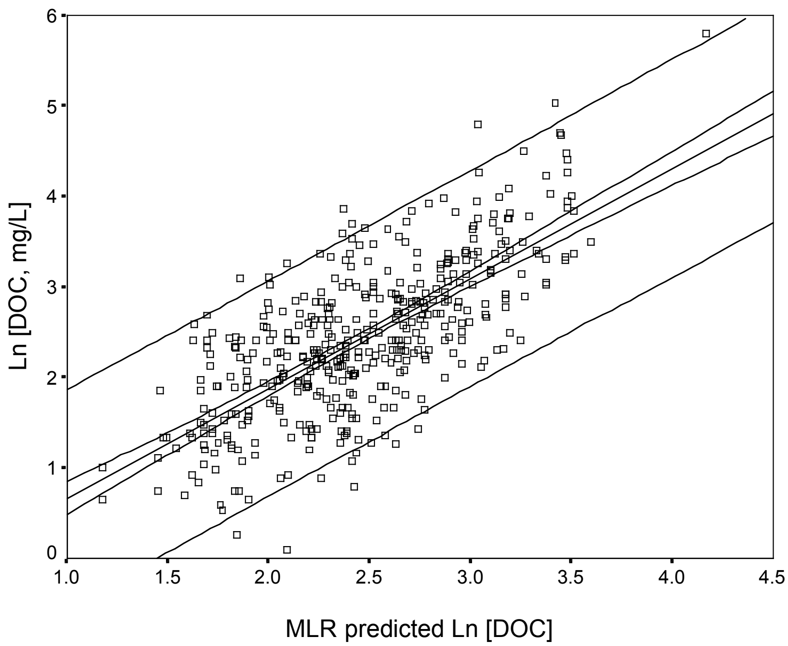


Figure 3-6 Validation data set for DOC vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(DOC) and individual predicted Ln(DOC).

Ln(Y) = 4.113 - .404 *Ln(*EventRain*) + .123*Ln(*AntDry*) - .129*CubeRoot(*CumPrecip*)
R^2 = .504

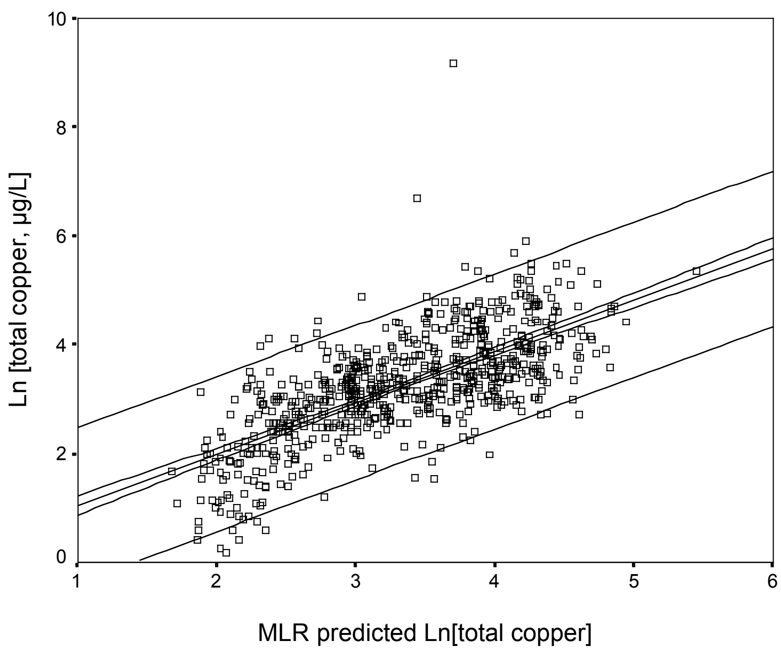


Figure 3-7 Validation data set for total copper vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(total copper) and individual predicted Ln(total copper).

Ln(y) = 2.9 - .161 *Ln(EventRain) + .163*Ln(AntDry) - .079*CubeRoot(CumPrecip) + 6.823*AADT*10-6
R^2 = .480

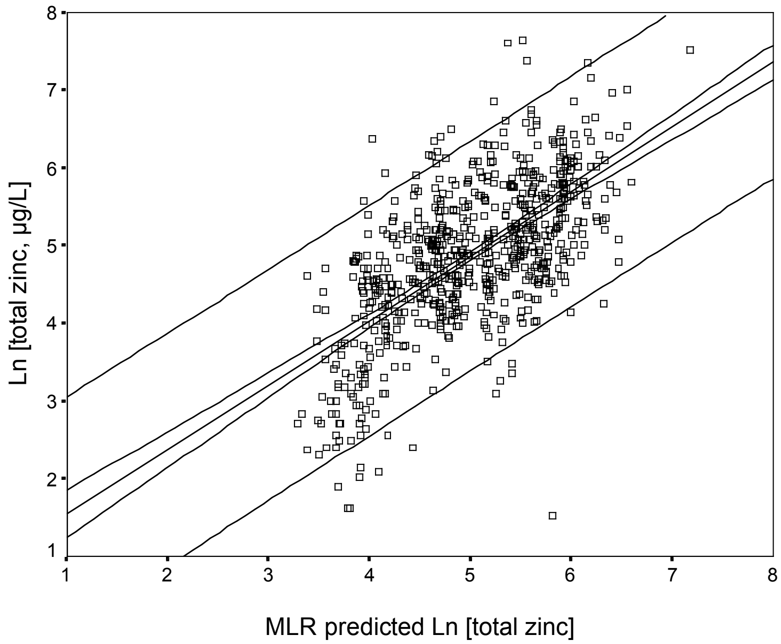


Figure 3-8 Validation data set for total zinc vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(total zinc) and individual predicted Ln(total zinc).

Ln(y) = 4.827 - .227 *Ln(EventRain) + .143*Ln(AntDry) - .084*CubeRoot(CumPrecip) + 6.747*AADT*10-6
R^2 = .405

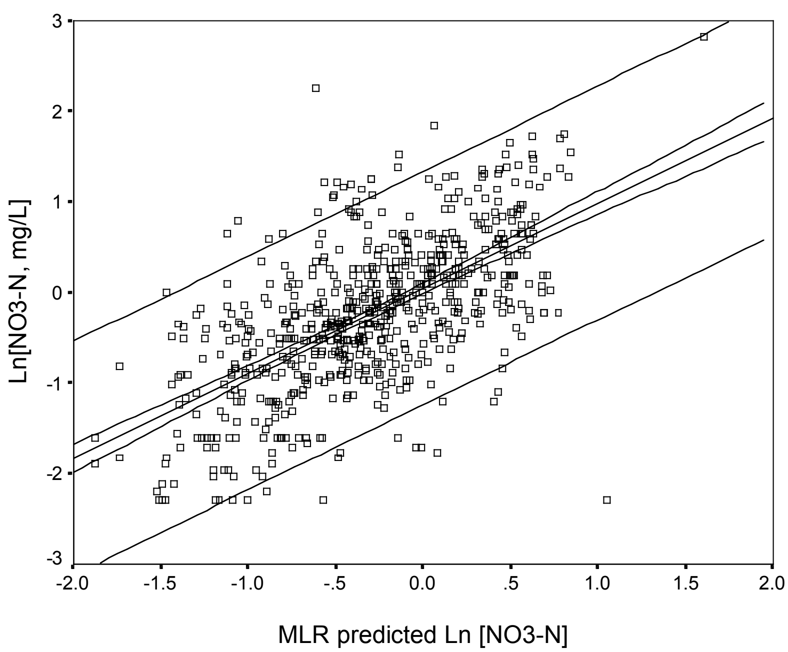


Figure 3-9 Validation data set for nitrate vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(NO_3-N) and individual predicted Ln(NO_3-N).

Ln(y) = 1.299 - .417 *Ln(EventRain) + .092*Ln(AntDry) - .090*CubeRoot(CumPrecip) - .0072*Ln(DrainageArea) + 2.870*AADT*10-6
R^2 = .405

Annual, Seasonal, and Intra-Event Variation

Annual Variation and Trends

Annual variability in runoff quality was assessed using ANOVA methods. Results of ANOVA analyses of the effects of annual variation on runoff quality are summarized in Table 3-13 for Department facilities monitored as part of the Statewide characterization studies. Annual variability in runoff quality was significant for a variety of constituents, but was generally small in most cases. Note that because the data cover only three monitoring years, these conclusions should not be extrapolated to longer-term patterns of annual variation. Patterns in annual variation for the three year period monitored are summarized below:

- Conventional parameters (organic carbon, EC, hardness, pH, TDS, temperature, and TSS) generally exhibited the highest annual variability, and annual variation was significant in 29 of 48 comparisons for conventional parameters. Annual variability tended to be higher for vehicle inspection facilities, park-and-ride facilities, rest areas, and toll plazas, with significant variation ranging from 5% - 42% in median runoff quality (depending on parameter and facility). Annual variation was typically lower for highway sites and maintenance stations, with significant variations in median runoff quality less than 10% for all conventional parameters.

- Trace metals generally exhibited low or insignificant annual variability. Annual variation was significant in 31 of 84 cases for trace metals (with each case consisting of the data for one parameter and one facility type). Annual variability in trace metals was generally not significant at Caltrans vehicle inspection facilities and toll plaza sites. Variation tended to be higher for rest areas and maintenance facilities, with significant variation ranging from 7% - 55% in median runoff quality (depending on parameter and facility). Annual variation was typically lowest for highway sites and maintenance stations, with significant variation in median runoff quality of less than 5% for all metals.

- Nutrients (nitrate, orthophosphate, total phosphorus, and TKN) generally exhibited the most frequently significant annual variation, with significant variation in 16 of 24 comparisons. However, the contribution of annual variability was typically low (not significant or less than or equal to 10%) for most parameters and facilities. Annual variation in median runoff quality for nutrients was highest for rest areas, with significant annual variation in median orthophosphate concentrations (30%), total phosphorus (17%), and TKN (19%) for this category of facility.

Seasonal Variation

The effect of the seasonal variation on runoff quality was assessed by evaluating the effect of cumulative seasonal precipitation on runoff quality in the MLR models. Cumulative seasonal precipitation exhibited a significant negative effect in every MLR model indicating that pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. Cumulative seasonal precipitation had a statistically significant effect in the MLR models for every Statewide characterization studies constituent evaluated, and significant coefficients for this factor were negative in every case. Preliminary results from the Department's First Flush

Characterization study (summarized in Appendix _) also reported a significant seasonal first flush effect for many pollutants in runoff.

Intra-Event Variation ("First Flush")

The effect of an intra-event first flush was evaluated using the MLR results for Event Rainfall (the total amount of rainfall recorded for a specific storm event). The results of these analyses indicated that increasing amounts of rainfall tended to result in a decrease in pollutant concentrations in runoff. This was interpreted to mean that the highest concentrations of pollutants occurred in runoff from the early part of the storm event, with concentrations becoming more dilute with increasing rainfall amounts. This indirect evidence of significant intra-event first flush effect was observed for nearly every conventional, trace metal, and nutrient parameter, and has been corroborated by the preliminary results from the Department's First Flush Characterization study, which was designed specifically to address this question.

Table 3-13 Annual Variation in Runoff Quality, Statewide Characterization Studies Data for Caltrans Facilities, 2000/01-2002/03

Pollutant Category	Parameter	Fraction	Proportion (%) of variation in runoff quality due to annual variation					
			CVIF	Highway	Maintenance	Parking	Rest Area	Toll Plaza
Conventional	DOC		26	6	ns	15	42	27
	EC		NS	4	ns	10	27	ns
	Hardness as $CaCO_3$		NS	6	9	14	ns	ns
	pH		NS	11	7	5	ns	ns
	TDS		NS	3	ns	9	24	ns
	Temperature		—	4	ns	ns	ns	—
	TOC		29	7	6	18	28	24
	TSS		11	2	8	4	ns	30
Trace Metals	As	Dissolved	NS	2	15	5	ns	ns
	As	Total	NS	1	18	4	ns	ns
	Cd	Dissolved	NS	2	ns	4	ns	ns
	Cd	Total	NS	2	8	ns	ns	ns
	Cr	Dissolved	NS	ns	ns	5	ns	ns
	Cr	Total	NS	ns	ns	12	28	ns
	Cu	Dissolved	NS	ns	13	4	40	ns
	Cu	Total	NS	ns	8	ns	55	ns
	Ni	Dissolved	NS	2	ns	ns	ns	ns
	Ni	Total	NS	2	ns	ns	18	ns
	Pb	Dissolved	NS	ns	ns	ns	ns	ns
	Pb	Total	NS	3	ns	4	31	28
	Zn	Dissolved	18	1	18	ns	26	ns
	Zn	Total	NS	3	15	ns	38	ns
Nutrient	NO_3-N		NS	2	7	10	ns	ns
	Ortho-P	Dissolved	NS	2	13	4	30	ns
	P	Total	NS	3	8	ns	17	ns
	TKN		21	5	10	10	19	18

Note:" – " indicates paramter wasnot monitored at this location.
"ns" indicates annual variation was not statistically significant at the 95% confidence level.

Runoff Quality from Different Facilities

Differences in runoff quality from different Caltrans facilities were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of ANCOVA analyses of differences in runoff quality for different Caltrans facilities are presented in Table 3-14. Summary statistics for the Statewide characterization studies data are also provided in Table 3-15. Caltrans facilities exhibited significant differences in runoff quality for all constituents except TKN. A significant result for the ANCOVA analysis indicates that at least one of the six facilities was significantly different from the overall average at the 95% confidence level. It does not indicate that every facility type is significantly different from every other facility type.

The results of these comparisons were as follows:

- **Conventional parameters:** Highway sites exhibited higher conventional pollutant concentrations in runoff than other facilities for DOC, EC, hardness, and TDS. Maintenance facilities, park-and-ride sites, and rest areas generally exhibited lower conventional pollutant concentrations in runoff. Toll plazas had higher than average concentrations of TOC and TSS in runoff, and lower pH. CVIF sites were generally not significantly different from overall average concentrations.
- **Trace metals:** Highway and toll plaza sites generally exhibited higher than average trace metal concentrations in runoff. Park-and-ride sites, and rest areas generally exhibited lower metals concentrations in runoff, and CVIF sites were typically not significantly different from average runoff quality. The exceptions to this pattern included arsenic and zinc, which were higher in maintenance facilities and CVIF runoff.
- **Nutrients:** Nutrient concentrations in highway runoff were not significantly different from the overall average, with the exception of NO_3-N. Maintenance facilities had consistently lower than average nutrient concentrations. There were no consistent patterns in nutrient concentrations for runoff from other facilities.

In general, these results indicate that higher pollutant concentrations in runoff are seen for facilities with generally higher vehicle traffic rates, as expected for highway and toll plaza sites. This pattern also corroborates the results of the MLR analyses, which established that higher AADT is associated with higher concentrations of most pollutant concentrations. Figure 3-10 and Figure 3-11 are provided to illustrate the interpretation of the pattern of differences in runoff quality from different facilities for TOC (Figure 3-10) and Nitrate (Figure 3-11).

Table 3-14 Significant Differences in Runoff Quality from Caltrans Facilities.

Pollutant Category	Parameter	Fraction	Significant Variation due to Facility Type?	Facilities with Significant Differences from Overall Facility Average Runoff Quality	
				Facilities Above Overall Average	**Facilities Below Overall Average**
Conventional	DOC		YES	HWY	PRK
	EC		YES	HWY	MAINT, PRK, REST
	Hardness as CaCO3		YES	HWY	MAINT, PRK, REST
	pH		YES	HWY	MAINT, PRK, REST, TOLL
	TDS		YES	HWY	MAINT, PRK, REST
	Temperature		NO	ns	ns
	TOC		YES	TOLL	PRK, REST
	TSS		YES	TOLL	PRK, REST
Trace Metals	As	Total	YES	MAINT	PRK, TOLL
	Cd	Total	YES	HWY, TOLL	PRK, REST
	Cr	Dissolved	YES	HWY, TOLL	CVIF, MAINT, PRK, REST
	Cr	Total	YES	HWY, TOLL	MAINT, PRK, REST
	Cu	Dissolved	YES	HWY, TOLL	PRK, REST
	Cu	Total	YES	HWY, TOLL	PRK, REST
	Ni	Dissolved	YES	HWY	PRK
	Ni	Total	YES	HWY, TOLL	PRK, REST
	Pb	Dissolved	YES	HWY	MAINT, PRK, REST
	Pb	Total	YES	HWY, TOLL	CVIF, PRK, REST
	Zn	Dissolved	YES	CVIF, MAINT, TOLL	HWY, PRK
	Zn	Total	YES	MAINT, TOLL	REST
Nutrient	NO3-N		YES	HWY	MAINT, PRK
	Ortho-P	Dissolved	YES	CVIF, REST	TOLL
	P	Total	YES	REST	MAINT
	TKN		NO	ns	ns

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Facility Type Designations: CVIF=Caltrans Vehicle Inspection Facility, HWY = Highway, MAINT = Maintenance, PRK = Park-and-Ride, REST = Rest Area, TOLL = Toll Plaza.

Table 3-15 Summary statistics for parameters monitored by the CALTRANS Statewide Characterization Study: Mean and Standard Deviation for Facilities.

Pollutant Category	Parameter	Units	Facility											
			CVIF		Hwy		Maintenance		Parking		Rest Area		Toll Plaza	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Conventional	DOC	mg/L	18.5	15.9	18.7	26.2	18.2	18.2	18.0	28.6	19.9	39.6	25.6	19.8
	EC	µS/cm	113.3	137.3	96.1	73.4	80.9	110.6	63.5	65.8	78.2	132.0	118.9	100.2
	Hardness as CaCO3	mg/L	33.5	22.1	36.5	34.2	26.7	28.7	26.6	45.9	33.0	81.2	37.1	27.7
	Chloride	mg/L	—	—	265.9	388.0	—	—	—	—	—	—	—	—
	pH	pH	7.1	0.4	7.1	0.7	6.8	0.6	6.8	0.7	6.9	0.4	6.9	0.4
	TDS	mg/L	84.8	92.1	87.3	103.7	68.9	78.1	61.7	78.3	61.2	130.0	81.5	74.2
	Temperature		12.5	3.3	12.5	3.4	12.5	2.8	12.6	3.4	11.4	3.2	12.3	3.0
	TOC	mg/L	20.0	16.9	21.8	29.2	20.6	23.0	18.6	20.6	22.2	40.5	31.0	20.3
	TSS	mg/L	83.4	53.0	112.7	188.8	96.4	95.0	68.5	59.3	63.3	54.4	123.3	77.4
	Turbidity	NTU	—	—	—	—	144.83	92.23	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	4.95	11.41	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	3.72	3.31	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	IDD	IDD	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	2.71	3.40	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	1.0	0.4	1.0	1.4	9.5	17.3	0.7	0.6	1.4	3.3	0.8	0.4
	As, total	µg/L	3.4	16.1	2.7	7.9	12.8	23.1	1.4	5.9	3.6	11.4	1.5	0.8
	Cd, dissolved	µg/L	0.20	0.16	0.24	0.54	0.27	0.22	0.12	0.12	IDD	IDD	0.43	0.29
	Cd, total	µg/L	0.56	0.40	0.73	1.61	0.69	0.63	0.30	0.30	0.32	0.53	1.15	0.56
	Cr, dissolved	µg/L	1.8	1.2	3.3	3.3	1.4	1.0	1.0	0.9	1.9	2.5	5.1	2.5
	Cr, total	µg/L	8.1	4.8	8.6	9.0	5.1	4.3	4.0	4.2	4.8	3.8	12.5	7.7
	Cu, dissolved	µg/L	15.6	13.3	14.9	14.4	14.3	17.6	8.7	8.8	9.6	12.0	27.3	20.6
	Cu, total	µg/L	33.6	24.1	33.5	31.6	29.5	37.6	17.1	15.2	16.0	14.2	59.6	23.0
	Hg, dissolved	ng/L	IDD	IDD	—	—	27.7	51.4	IDD	IDD	—	—	IDD	IDD
	Hg, total	ng/L	IDD	IDD	36.7	37.9	65.4	83.7	57.3	73.6	—	—	IDD	IDD
	Ni, dissolved	µg/L	3.5	2.4	4.9	5.0	3.7	4.0	3.3	3.9	3.2	5.8	6.0	4.5
	Ni, total	µg/L	8.4	4.7	11.2	13.2	7.9	7.7	6.2	4.8	7.3	8.3	13.7	6.8
	Pb, dissolved	µg/L	2.7	3.9	7.6	34.3	1.6	3.0	1.3	2.7	1.2	1.7	5.2	5.2
	Pb, total	µg/L	21.9	37.7	47.8	151.3	21.3	26.5	10.3	11.5	7.7	8.0	31.6	24.3
	Zn, dissolved	µg/L	88.2	79.1	68.8	96.6	21.3	26.5	10.3	11.5	82.5	263.7	123.7	89.4
	Zn, total	µg/L	244.5	151.6	187.1	199.8	245.6	259.3	154.3	157.1	142.4	298.9	292.9	131.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	1132	1621	—	—	—	IDD	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	13438	34299	—	—	—	IDD	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	1.08	1.46	—	—	—	IDD	—	—	—	—
	NO3-N	mg/L	0.89	0.81	1.07	2.44	0.74	1.13	0.57	IDD	0.96	0.88	0.84	0.81
	Ortho-P, dissolved	mg/L	0.13	0.12	0.11	0.18	0.09	0.40	0.15	IDD	0.44	1.67	0.05	0.05
	P, total	mg/L	0.28	0.16	0.29	0.39	0.23	0.20	0.33	0.42	0.47	0.53	0.25	0.11
	TKN	mg/L	2.16	2.72	2.06	1.90	1.79	1.72	2.28	2.20	4.37	14.04	2.38	1.59
Pesticide	Chlorpyrifos	µg/L	—	—	—	—	IDD	IDD	—	—	—	—	—	—
	Diazinon	µg/L	IDD	IDD	0.13	0.29	0.12	0.30	IDD	IDD	—	—	IDD	IDD
	Diuron	µg/L	—	—	4.60	18.24	—	—	—	—	IDD	IDD	—	—
	Glyphosate	µg/L	—	—	19.61	26.97	—	—	—	—	IDD	IDD	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Acenaphthylene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Chrysene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Fluorene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Naphthalene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Phenanthrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Pyrene	µg/L	—	—	0.05	0.03	—	—	IDD	IDD	—	—	—	—

Notes: "IDD" indicates that there were insufficient detected data to calculate statistic.
"– " indicates parameter was not monitored Statewide characterization studies for this facility.

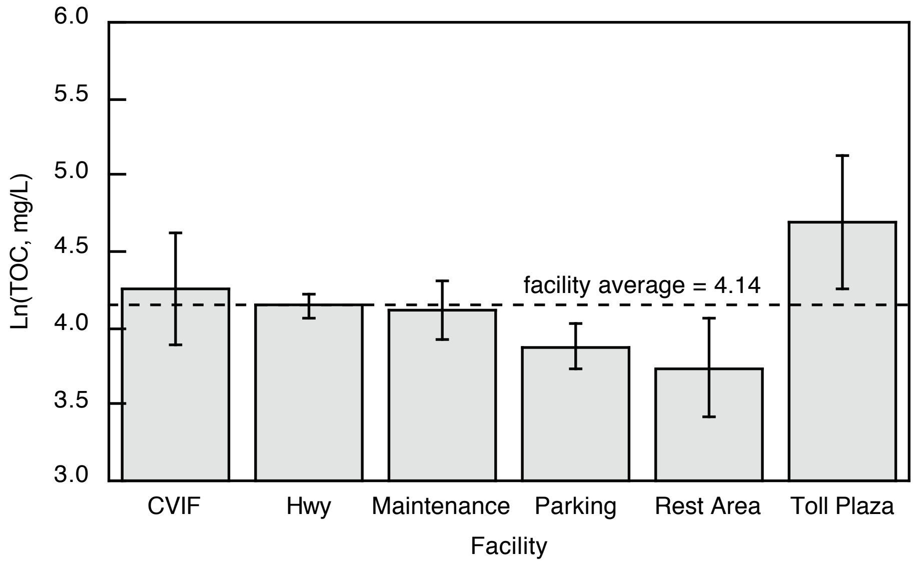


Figure 3-10
Estimated Marginal Means and 95% confidence limits for TOC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions.

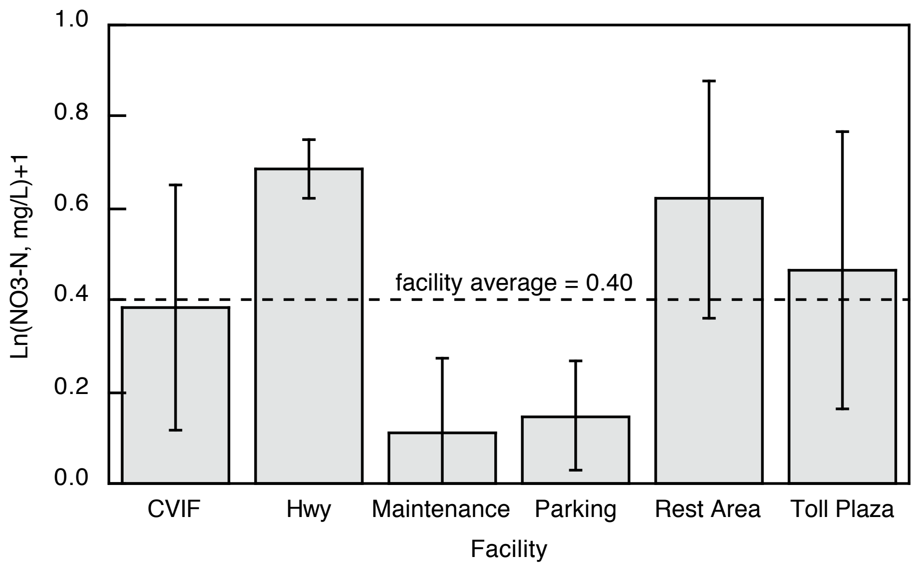


Figure 3-11
Estimated Marginal Means and 95% confidence limits for Nitrate

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions.

Geographic Variation Analysis Results

The effects of geographic region on stormwater runoff quality from highways were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of these analyses are summarized in Table 3-16. Geographic region exhibited significant effects on runoff quality for most constituents (exceptions were pH, temperature, and dissolved zinc). A few broadly defined patterns emerged for this factor:

- ***Conventional parameters:*** Highway sites in the Central and Southern Coast Ranges, the Klamath Mountains, and the Central Coast region generally exhibited higher conventional pollutant concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Temperate Desert region generally exhibited lower conventional pollutant concentrations in runoff.

- ***Trace metals:*** Highway sites in the Klamath Mountains, the Central Valley, and the Central Coast region generally exhibited higher trace metals concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Temperate Desert region generally exhibited lower metals concentrations in runoff.

- ***Nutrients:*** Highway sites in the Central Valley, the North Coast Interior Range, and the Central and Southern Coast Ranges generally exhibited higher nutrient concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Central Coast region generally exhibited lower nutrient concentrations in runoff.

Note that the numbers of sites monitored were limited for some regions (North Coast Range and Interior Range, Klamath Mountains, Temperate Desert), as these areas are characterized by relatively fewer highway miles; results of the geographical variation analysis for these regions therefore should be interpreted with a degree of caution. Figure 3-12 illustrates Caltrans monitoring locations and geographic regions. Figure 3-13 and Figure 3-14 are provided to illustrate the interpretation of the pattern of differences in runoff quality from different geographic regions for Total copper (Figure 3-13) and EC (Figure 3-14).

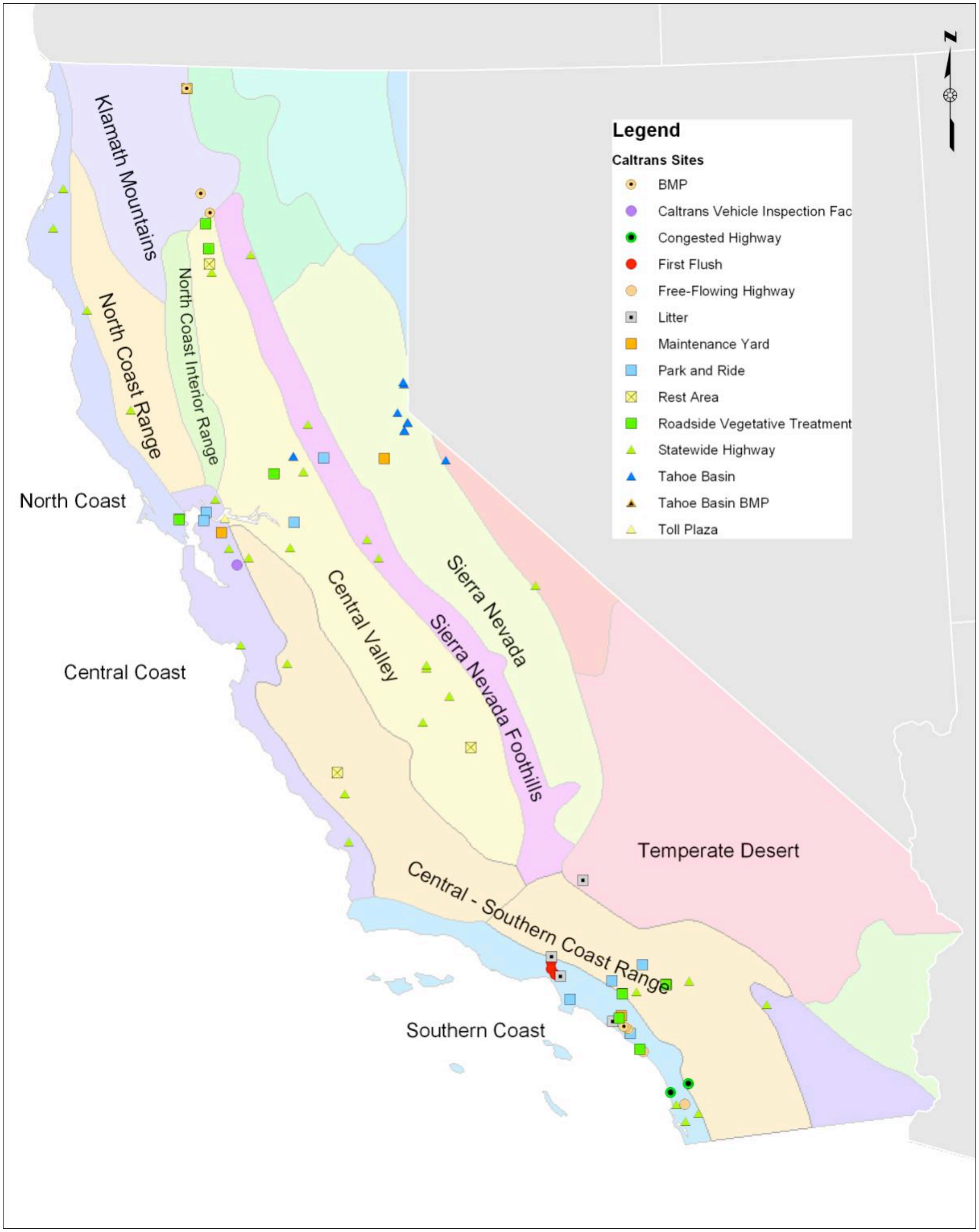


Figure 3-12 Geographic Regions and Caltrans Monitoring Sites

Table 3-16 Effect of Geographic Region on Highway Runoff Quality.

Pollutant Category	Parameter	Fraction	Significant Variation due to Geographic Region?	Regions with Significant Differences from Overall Average Runoff Quality for Geographic Regions	
				Regions Above Overall Average	**Regions Below Overall Average**
Conventional	DOC		YES	C/SCR	SNF
	EC		YES	CC, CV, C/SCR, NC, SC	SNF, TD
	Hardness as $CaCO_3$		YES	C/SCR	SNF, TD
	pH		NS	ns	ns
	TDS		YES	C/SCR	SNF
	Temperature		NS	ns	ns
	TOC		YES	CC, C/SCR, SC	SNF
	TSS		YES	CC, CV, C/SCR, KLM	ns
Trace Metals	As	Total	YES	ns	SNF
	Cd	Total	YES	CV, C/SCR	ns
	Cr	Dissolved	YES	CC, KLM, SC	C/SCR, SNF
	Cr	Total	YES	CC, CV, KLM	SNF
	Cu	Dissolved	YES	CC, CV	C/SCR, SNF
	Cu	Total	YES	CC, CV, SC	SNF
	Ni	Dissolved	YES	ns	SNF
	Ni	Total	YES	CC, KLM	SNF
	Pb	Dissolved	YES	ns	SNF
	Pb	Total	YES	CC, KLM	SNF
	Zn	Dissolved	NO	ns	ns
	Zn	Total	YES	CC, CV	NC, SNF
Nutrients	NO_3-N		YES	C/SCR, KLM	CC, SNF
	Ortho-P	Dissolved	YES	NCI	CC, SNF, SC
	P, total	Total	YES	CV, C/SCR, NCI	SNF
	TKN		YES	CV, C/SCR	SNF

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Abbreviations for Geographic Regions: CC=Central Coast, C/SCR=Central and Southern Coast Range, CV=Central Valley, NC=North Coast, NCR = North Coast Range, NCI = North Coast Interior Range, SC=Southern Coast, SNF= Sierra Nevada Foothills, TD =Temperate Desert, KLM=Klamath Mountains.

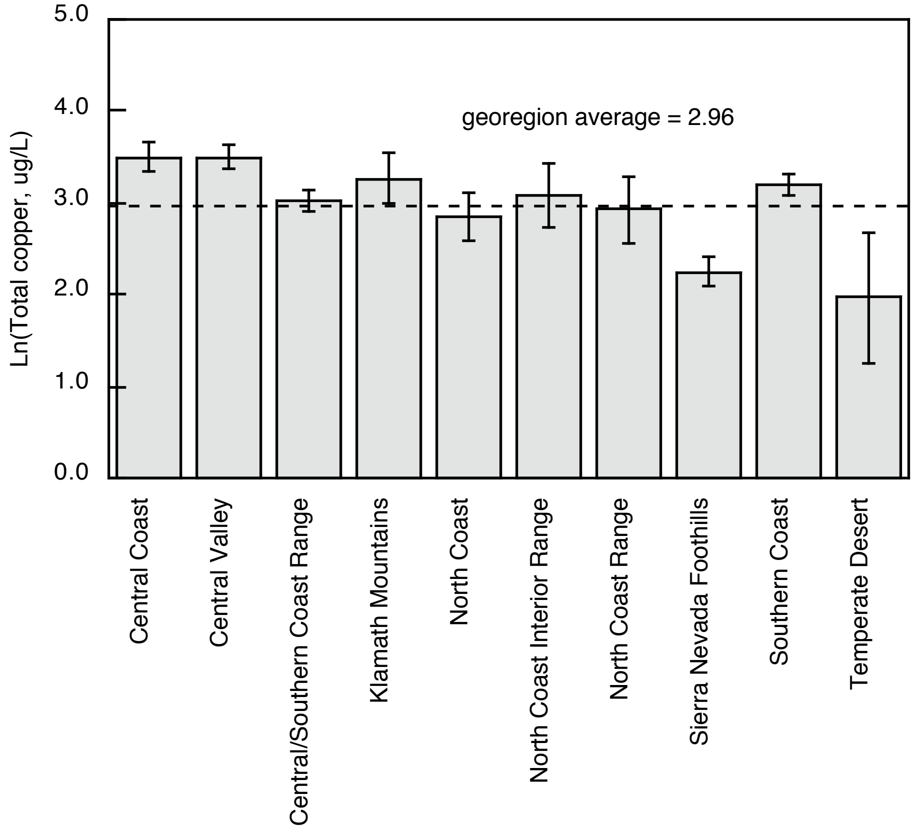


Figure 3-13
Estimated Marginal Means and 95% confidence limits for Total Copper

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average of georegions.

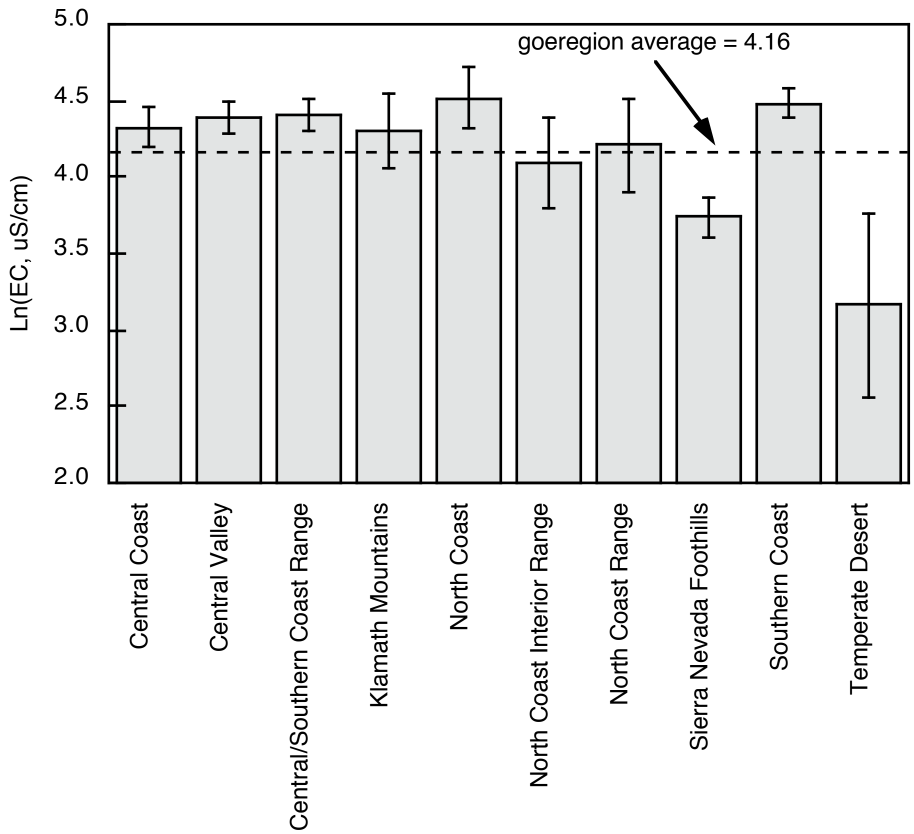


Figure 3-14
Estimated Marginal Means and 95% confidence limits for EC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average of georegions.

Effect of Predominant Surrounding Land Use

The effects of predominant surrounding land use on stormwater runoff quality from highways were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of these analyses are presented in Table 3-17. Surrounding land use contributed to significant differences in runoff quality from highway sites for all constituents except total chromium, dissolved lead, and NO_3-N. Patterns of significant differences in runoff quality from different predominating land uses are summarized as follows:

- **Conventional parameters**: Runoff from highway sites in agricultural and commercial areas exhibited higher concentrations of most conventional pollutants (EC, DOC, TDS, TOC, TSS) than the overall average and all other land uses. Highway sites in predominantly residential, transportation, and open land use areas generally exhibited lower than average conventional pollutant concentrations in runoff.
- **Trace metals:** Runoff from highway sites in agricultural and commercial areas also exhibited consistently higher concentrations of most trace metals than for other land uses. Predominantly residential, transportation, and open land use areas generally exhibited average or lower than average metals pollutant concentrations in runoff. Exceptions to this pattern were total and dissolved copper and total and dissolved zinc, which were significantly higher than average in transportation areas.
- **Nutrients:** Nutrient concentrations in highway runoff followed the same general pattern. Total phosphorus, and TKN were significantly higher in agricultural and commercial areas, and orthophosphate was also higher in agricultural area. Other land uses generally nutrient concentrations that were not significantly different from the overall average.

Figure 3-15 and Figure 3-16 are provided to illustrate the interpretation of the pattern of differences in runoff quality for different surrounding land uses for EC (Figure 3-15) and total copper (Figure 3-16).

Table 3-17 Significant Variation Due to Surrounding Land Use

Pollutant Category	Parameter	Fraction	Significant Variation due to Surrounding Land Use?	Land Uses with Significant Differences from Overall Average Runoff Quality for Land Uses	
				Land Uses Above Overall Average	**Land Uses Below Overall Average**
Conventional	DOC		YES	AG	TRANS
	EC		YES	AG, COMM	RES, TRANS
	Hardness as CaCO3		YES	AG, TRANS	RES
	pH		YES	COMM, OPEN	TRANS
	TDS		YES	AG, COMM	ns
	Temperature		YES	RES	OPEN
	TOC		YES	AG, COMM, MXD	OPEN, RES
	TSS		YES	AG, COMM	ns
Trace Metals	As	Total	YES	COMM	MXD
	Cd	Total	YES	COMM	ns
	Cr	Dissolved	YES	OPEN	TRANS
	Cr	Total	NO	ns	ns
	Cu	Dissolved	YES	AG, TRANS	OPEN, RES
	Cu	Total	YES	AG, COMM	OPEN, RES
	Ni	Dissolved	YES	AG	TRANS
	Ni	Total	YES	AG, COMM	TRANS
	Pb	Dissolved	NO	ns	ns
	Pb	Total	YES	AG, COMM	TRANS
	Zn	Dissolved	YES	TRANS	OPEN
	Zn	Total	YES	AG, COMM, TRANS	MXD, OPEN, RES
Nutrient	NO3-N		NO	ns	ns
	Ortho-P	Dissolved	YES	AG	TRANS
	P	Total	YES	AG, COMM	ns
	TKN		YES	AG, COMM, TRANS	OPEN

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Land Use designations: AG = Agriculture, COMM = Commercial, MXD = Mixed, no dominant land use determined, OPEN = Open, RES = Residential, TRANS=Transportation

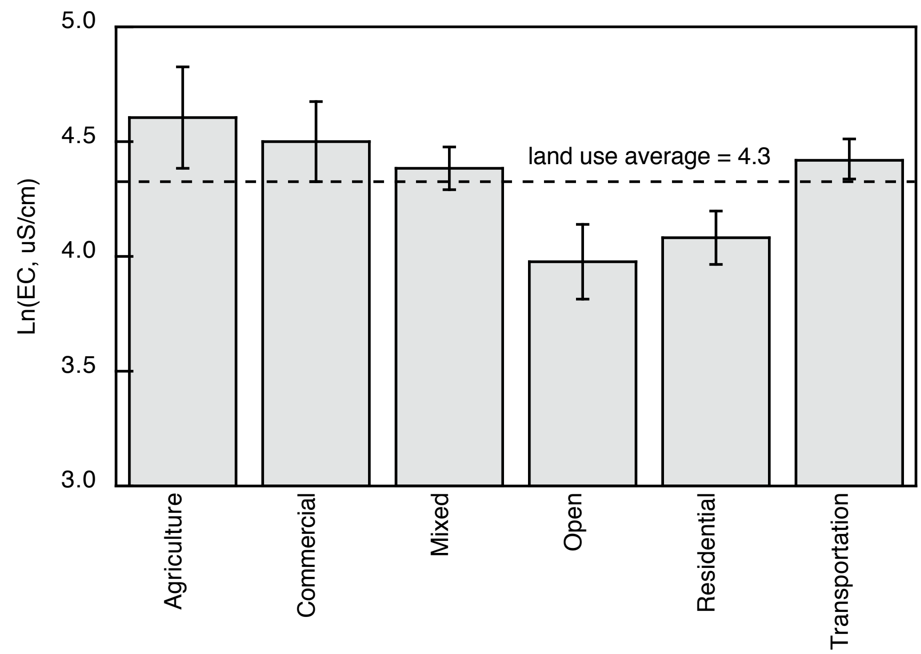


Figure 3-15 Estimated Marginal Means and 95% confidence limits for EC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average for land uses.

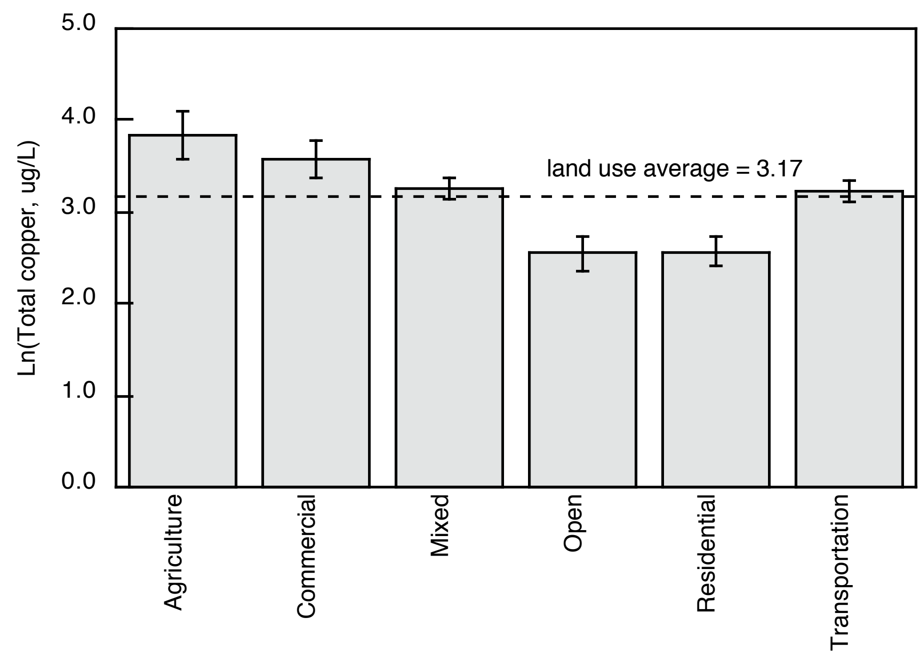


Figure 3-16 Estimated Marginal Means and 95% confidence limits for Total Copper

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average for land uses.

Comparisons with Water Quality Objectives

For the purpose of prioritizing constituents for future BMP implementation and study, runoff quality data were compared to California Toxics Rule (CTR) objectives (USEPA 2000) and to several other surface water quality objectives considered potentially relevant to stormwater runoff quality. The sources of other water quality objectives considered were National Primary Drinking Water Maximum Contaminant Levels (USEPA 2002), U.S. EPA Action Plan for Beaches and Recreational Waters (USEPA 1999a), U.S. EPA Aquatic Life Criteria (USEPA 1999b), California Department of Health Services Drinking Water MCLs (CDHS 2002), and California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos (Siepman and Finlayson 2000). In the case of CTR metals objectives that are adjusted for hardness, the objective was based on the lowest observed hardness for the data set for the most stringent assessment of percent exceedance.

These surface water quality objectives were considered relevant for comparison to stormwater quality because they apply to surface waters which may receive stormwater discharges from highways and other Caltrans facilities. Because these water quality objectives apply to receiving waters, and not directly to runoff, the comparisons are useful only as general guidelines for identifying pollutants with a higher priority for management, and do not reflect regulatory compliance status. Constituents were prioritized according to their estimated percent exceedance of the most stringent water quality objective, i.e. parameters with a higher percent exceedance received a higher monitoring priority, with greater 50% exceedance receiving *high* priority, 5–50% receiving a *medium* priority, and less than 5% receiving a *low* priority. Estimated percent exceedance was calculated based on the distributional parameters calculated for each constituent, using the statistical methods described previously for characterization of runoff quality (Section 2, page 17). Specifically, percent exceedance was estimated as the cumulative probability of exceeding the specific water quality objective, based on the normal or lognormal distribution statistics, as appropriate for the constituent of interest.

Runoff concentrations of most pollutants were observed to exceed the most stringent receiving water quality objectives, and a few parameters exceeded the objectives in a majority of runoff samples. It should be noted that the water quality objectives cited are not intended to apply specifically to stormwater discharges, and are used here only in the context of establishing priorities for continued monitoring. It should also be noted that many constituents monitored do not have relevant water quality objectives. The results of comparisons with the most stringent CTR and other relevant water quality objectives are provided in Table 3-18, and summarized below. Constituents that were monitored by Caltrans in stormwater runoff, but without relevant surface water quality objectives, are listed in Table 3-19.

- Copper, lead, and zinc were estimated to exceed their CTR surface water quality objectives for dissolved and total fractions in greater than 50% of samples.
- Dissolved fractions of cadmium and nickel were estimated to exceed CTR surface water quality objectives in less than 3% of runoff samples, while total fractions of cadmium and nickel were estimated to exceed CTR objectives in 22% and 15% of runoff samples,

respectively. Dissolved arsenic and chromium were estimated to exceed CTR objectives in fewer than 0.01% of runoff samples, while total fractions of arsenic and chromium were estimated to exceed objectives in approximately 5% and 2% of runoff samples, respectively.

- In all cases, trace metals exceeded objectives based on total fractions much more frequently than objectives for dissolved fractions.
- Of the trace organics (semi-volatile organic compounds), only benzo(b)fluoranthene was observed to exceed its CTR objective. Other trace organic compounds were not detected or not expected to exceed CTR objectives more frequently than in 0.01% of runoff samples. Note that because SVOCs were only monitored for highway facilities for a total of 32 samples, these results can not be generalized to other facilities.
- In comparisons with relevant non-CTR criteria, TDS, nitrate, and nitrite were estimated to exceed the drinking water MCLs for these parameters in less than 4% of samples.
- Total aluminum and iron were estimated to exceed their chronic U.S. EPA Aquatic Life Criteria in nearly 100% and 70% of runoff samples, respectively. It should be noted that these metals were monitored for a relatively few events and sites, and these results should not be generalized to all facility types. Chloride was estimated to exceed the chronic U.S. EPA Aquatic Life Criterion in 32% of samples.
- Diazinon was estimated to exceed the California Department of Fish and Game (CDFG) recommended chronic criterion in 79% of stormwater runoff samples, and chlorpyrifos was estimated to exceed the CDFG recommended chronic criterion in 73% of samples.
- Total and fecal coliforms were estimated to exceed the California Department of Health Services Action Level (for recreational beach use) in 21% and 43% of samples, respectively. These parameters were monitored only at selected highway and construction sites for a limited number of events.

Table 3-18 Comparisons of Caltrans runoff quality data with CTR and other relevant water quality objectives

Parameter	Units	Mean	Standard Deviation	Max Detected Value	CTR Objective	Other Objective	Source of non-CTR objective[1]	Estimated % exceedance	Rank[4]
Parameters with CTR Objectives									
Pb, total	µg/L	49	142	2600	0.66	15	—	97.2%	HIGH
Cu, total	µg/L	39	262	9500	3.2	1000	—	97.1%	HIGH
Cu, dissolved	µg/L	14	15	195	3.1	—	—	88.0%	HIGH
Zn, total	µg/L	207	286	4800	41	—	—	86.8%	HIGH
Pb, dissolved	µg/L	4.5	21.3	480	0.64	—	—	61.1%	HIGH
Zn, dissolved	µg/L	75	128	3320	40	—	—	51.7%	HIGH
Cd, total	µg/L	0.76	1.26	30	0.97	5	MCL	22.4%	MED
Ni, total	µg/L	13	67	2420	18	100	MCL	15.3%	MED
As, total	µg/L	3.3	8.9	91	150	10	MCL	4.7%	LOW
Cd, dissolved	µg/L	0.23	0.39	8.4	0.93	—	—	2.6%	LOW
Ni, dissolved	µg/L	4.2	5.3	98	18	—	—	1.9%	LOW
Cr, total	µg/L	10	21	620	76	50	CA DHS	1.8%	LOW
Benzo(b)fluoranthene (2)	µg/L	IDD	IDD	0.05	0.0044	—	—	(3)	LOW
Cr, dissolved	µg/L	2.9	4.9	141	65	—	—	0.01%	LOW
As, dissolved	µg/L	1.7	5.1	81	150	—	—	0.001%	LOW
Acenaphthene (2)	µg/L	IDD	IDD	0.25	1200	—	—	<0.01%	LOW
Fluoranthene (2)	µg/L	IDD	IDD	0.1	300	—	—	<0.01%	LOW
Fluorene (2)	µg/L	IDD	IDD	0.06	1300	—	—	<0.01%	LOW
Pyrene (2)	µg/L	0.05	0.03	0.13	960	—	—	<0.01%	LOW
Anthracene (2)	µg/L	IDD	IDD	ND	9.6	—	—	ND	LOW
Benzo(a)anthracene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Benzo(a)pyrene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Chrysene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Dibenzo(a,h)anthracene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Indeno(1,2,3-c,d)pyrene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Parameters with Other Relevant Objectives									
Al, total (2)	µg/L	8863	9746	31430	none	87	EPA AL	99.9%	HIGH
Diazinon (2)	µg/L	0.17	0.20	1.0914	none	0.05	CA DFG	78.8%	HIGH
Chlorpyrifos (2)	µg/L	0.044	0.08	0.97	none	0.014	CA DFG	72.6%	HIGH
Fe, total (2)	µg/L	6794	6794	43500	none	1000	EPA AL	69.2%	HIGH
Fecal Coliform Bacteria (2)	MPN/100 ml	1415	3029	16000	none	400	EPA AP	42.6%	MED
Chloride (2)	mg/L	280	407	1800	none	230	EPA AL	32.4%	MED
Total Coliform Bacteria (2)	MPN/100 ml	9169	25975	160000	none	10000	EPA AP	21.2%	MED
TDS	mg/L	139	466	11700	none	500	MCL	3.5%	LOW
NO_2-N (2)	mg/L	0.14	0.30	2.8	none	1	MCL	1.5%	LOW
NH_3-N (2)	mg/L	0.71	1.48	24.66	none	5.91	EPA AL	0.6%	LOW
NO_3-N	mg/L	0.93	1.50	48	none	10	MCL	0.3%	LOW

Table Notes: IDD indicates insufficient detected data to estimate statistic. ND indicates constituent was not detected.

(1) MCL = U.S. EPA Drinking Water Maximum Contaminant Level, DHS = California Department of Health Services, EPA AL = U.S. EPA Aquatic Life Criterion, CA DFG = California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos. (2) Parameter is not included on Caltrans Minimum Constituent List for Runoff Characterization. (3) Maximum observed value exceeded CTR objective, but there were insufficient detected data to estimate percent exceedance. (4) Rank is the assigned monitoring priority based on percent exceedance: HIGH—greater than 50% exceedance, MED–from 5-50% exceedance, LOW—less than 5% exceedance or infrequently detected in runoff.

Table 3-19 Statewide characterization studies constituents without CTR or other relevant water quality objectives

<table>
<tr><th>Conventional parameters</th><th>Hydrocarbons</th><th>Metals</th><th>Pesticides</th></tr>
<tr><td rowspan="3">BOD(1)
COD(1)
EC
Hardness
pH
Temperature
Organic carbon, total and dissolved
TSS
Turbidity(1)</td><td>Oil and Grease(1)
TPH (Diesel) (1)
TPH (Heavy Oil) (1)
TPH (Gasoline) (1)</td><td>Aluminum, dissolved(1)
Iron, dissolved(1)
Mercury, total and dissolved(1)</td><td rowspan="3">Diuron
Glyphosate
Oryzalin
Oxadiazon
Triclopyr</td></tr>
<tr><td>SVOCs</td><td>Nutrients</td></tr>
<tr><td>Acenaphthylene
Benzo(g,h,l,)perylene
Benzo(k)fluoranthene
Napthalene
Phenanthrene</td><td>Orthophosphate, dissolved
Phosphorus, dissolved(1)
Phosphorus, total
TKN</td></tr>
</table>

(1) Parameter is not included on Caltrans Minimum Constituent List for Runoff Characterization

Correlations Between Runoff Quality Parameters

Correlations between runoff quality parameters were screened using Spearman's non-parametric rank correlation procedure, and verified for significant linear relationship using Pearson's standard parametric procedure. Because of the large amount of data there were many correlations significant at the 95% confidence level. However, correlations with a Spearman's *rho*[1] value less than 0.8 were considered to be too weak for one parameter to serve as practical monitoring surrogate for the other parameter, even if correlations were significant. Significant correlations greater than 0.8 are summarized in Table 3-20, along with their corresponding Pearson's Product-Moment correlation coefficient, *R*. The complete Spearman's correlation matrix is presented in Appendix E.

Correlations were generally strongest within pollutant categories, with few correlations greater than 0.8 between constituents in different categories. Exceptions to this pattern included TSS with total aluminum and iron, and dissolved aluminum with ammonia nitrogen. Within the conventional parameters, the strongest correlations were observed among parameters associated with dissolved minerals (EC, TDS, and chloride), organic carbon (TOC and DOC), and suspended particulate materials (TSS and turbidity). Within the metals category, total concentrations of most metals were highly correlated, but correlations between total and dissolved concentrations were all less than 0.8, even between total and dissolved concentrations of the same metals. Total petroleum hydrocarbons were generally poorly correlated with all other parameters, but did exhibit a strong correlation between the diesel and heavy oil fractions of this category. Nutrients were generally not strongly correlated within the nutrient category or with other categories (with the odd exception of ammonia and dissolved aluminum). Total and fecal coliform bacteria exhibited no significant correlations greater than 0.8 within or outside the microbiological category.

These results suggest that for the purpose of assessing trends, the effectiveness of BMPs, and other pollutant management alternatives, some reductions in the parameters monitored would be practical:

- Organic carbon could be adequately monitored as either the total or dissolved fraction.
- Dissolved minerals could be adequately monitored as EC with estimates of TDS and chloride based on the relationship between these parameters.
- Suspended particulate matter could be adequately assessed by measurements of TSS, eliminating turbidity.
- TPH could be adequately monitored as either the diesel or the heavy oil fraction.
- Total aluminum and iron could be adequately monitored as TSS based on the relationship between these parameters.
- Correlations among total concentrations of the total fractions of several metals (cadmium, chromium, copper, lead, nickel, and zinc, as well as aluminum and iron) were consistently strong enough to monitor a select subset of these parameters to assess effectiveness of BMPs.

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[1] Spearman's *rho* is a non-parametric measure of association calculated from ranks. Spearmans's *rho* is analogous to the Pearson's Product-Moment correlation coefficient, *R*. In all cases, these values were nearly identical.

Table 3-20 Summary of correlations between runoff quality parameters. Spearman's *rho* > 0.8 and significant at the 95% confidence level.

Constituent Categories	Parameter Pairs	Spearman's *rho*	*n*	Pearson's R	*n*
Conventionals with Conventionals	TOC and DOC	0.962	1687	0.960	1677
	TSS and Turbidity	0.844	395	0.784	394
	EC and Chloride	0.976	27	0.970	27
	EC and TDS	0.794	1857	0.805	1799
	TDS and Chloride	0.891	27	0.876	27
Conventionals with Hydrocarbons	*None > 0.8*	—	—	—	—
Conventionals with Metals	TSS and Al, total	0.861	26	0.878	26
	TSS and Fe, total	0.891	59	0.898	59
Conventionals with Microbiologicals	*None > 0.8*	—	—	—	—
Conventionals with Nutrients	*None > 0.8*	—	—	—	—
Hydrocarbons with Hydrocarbons	TPH, Diesel and Heavy Oil	0.877	20	0.858	19
Hydrocarbons with other categories	*None > 0.8*	—	—	—	—
Metals with Metals	Al, total and Cd, total	0.814	28	0.823	25
	Al, total and Cr, total	0.893	28	0.951	28
	Al, total and Ni, total	0.822	28	0.879	26
	Cr, total and Fe, total	0.919	59	0.880	53
	Cu, total and Fe, total	0.863	59	0.872	59
	Cu, total and Pb, total	0.809	2231	0.792	2133
	Cu, total and Zn, total	0.857	2231	0.850	2224
	Fe, total and Ni, total	0.866	59	0.803	51
	Fe, total and Pb total	0.919	59	0.900	48
	Fe, total and Zn, total	0.822	59	0.842	59
Metals with Nutrients	Al, dissolved and NH_3-N	-0.901	14	-0.766	9
Metals with Microbiologicals	*None > 0.8*	—	—	—	—
Microbiologicals and other categories	*None > 0.8*	—	—	—	—
Nutrients and other categories	*None > 0.8*	—	—	—	—

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SECTION 4 DISCUSSION

The results of the runoff characterization monitoring performed by the Department, together with the analyses of the monitoring data presented in Section 3 of this report, provide adequate information to address the primary objectives of this report (listed in Section 1). Discussions of the results and interpretations of the analytical evaluations of stormwater runoff quality are presented below.

Effects of AADT and Other Factors on Runoff Quality, and Implications for Stormwater Management

Multiple Linear Regression (MLR) analyses of the Department's runoff quality data demonstrate a set of generally consistent relationships between runoff quality and precipitation factors, antecedent conditions, AADT, and drainage area. The results are generally consistent with—and provide qualitative validation of—models generated from previous analyses of the Department's stormwater runoff quality data (Kayhanian *et al*., 2003). However, the use of the more representative Statewide Characterization Study data for MLR analyses results in a more consistent picture of the effects of these factors than derived from the previous analysis.

The current results provide confirming evidence that traffic volumes and rainfall conditions – including antecedent conditions – are the most significant factors influencing runoff quality from the Department's facilities. Runoff quality is significantly correlated with traffic level; pollutant concentrations are higher for sites with higher AADT. Pollutant concentrations are also higher during events that occur at lower cumulative (seasonal) rainfall levels (i.e., those occurring earlier in the rainy season), and during storm events preceded by longer antecedent dry periods. Pollutant concentrations tend to decrease for storm events with higher event rainfall totals.

Larger drainage areas were also generally associated with lower pollutant concentrations for some parameters, but this effect was less consistent than the effects of AADT, event rainfall, cumulative precipitation, and antecedent dry period on runoff quality. Maximum rainfall intensity was not a statistically significant or consistent predictor of runoff quality for most constituents, due in part to correlation with event rainfall totals.

Seasonal and Event First Flush Effects

The MLR analyses indicate that pollutant concentrations decrease with increasing cumulative seasonal rainfall, and increase with antecedent dry period. California's climate is characterized by an extended summer dry season. The "first flush" rainfall event in the fall, with the longest annual antecedent dry period and the lowest cumulative seasonal rainfall total, is therefore expected to produce the highest runoff pollutant concentrations. The results of the current study are consistent with a significant seasonal "first flush effect," resulting in higher pollutant concentrations early in the wet season, with concentrations tending to decrease through the remainder of the wet season. The mechanism underlying these effects is generally understood to be the build-up of pollutants on exposed surfaces during dry weather, and wash-off during rainfall events.

A significant storm event first flush effect was also suggested for most pollutants by the statistically significant effect of storm event rainfall totals on pollutant concentrations. Although demonstration of a storm event first flush effect was not a specific goal of discharge characterization monitoring, this result suggests that concentrations of most pollutants monitored by the Department are significantly higher in the initial runoff of a storm event and tend to be diluted by additional rainfall and runoff. The Department is currently conducting studies designed specifically to address this question.

The findings of significant seasonal and storm event first flush effects confirm conclusions reached in other studies of these phenomena. The first year of results from a study conducted by UCLA and supported by the Department (Stenstrom *et al*. 2001) demonstrated a statistically significant storm event first flush effect for a number of pollutants. Analysis of stormwater runoff quality data from the City of Sacramento's Storm Water Monitoring Program have also demonstrated significant event and seasonal first flush effects for a variety of pollutants, as well as significant effects of precipitation factors and antecedent conditions (LWA 1996). The weight of evidence from these and other studies appear to provide compelling evidence of the relationships of these factors with stormwater runoff quality.

Effects of Categorical Factors on Runoff Quality

Several consistent differences were also found in the results of analyses of the effects of categorical factors (facility type, land use, and geographical region) on runoff quality. However, conclusions drawn from these results should be interpreted with caution. Although significant differences were found for most constituents for every category evaluated, the analyses and interpretation of the results are limited by some largely unavoidable imbalances in the sampling design. Specifically, most of the data for each categorical comparison was dominated by one district, geographical region, facility type, or land use, with few sites representing other levels of each category. Several land uses and geographic regions were represented by two sites with many sample events, resulting in pseudoreplication and artificial inflation of the significance of the effect of that categorical factor. This imbalance in design results in some uncertainty in interpreting the effects of specific land uses and geographic regions that must be acknowledged. Given this warning, the following patterns were noted in the Statewide characterizations studies data:

- The analysis of runoff quality from different facilities indicated that facilities expected to have the highest vehicle traffic, *e.g*. highways and toll plazas, exhibited elevated concentrations of most pollutants in runoff, compared to other facilities. Pollutant concentrations in runoff from lower traffic facilities (maintenance facilities, park-and-ride lots, Caltrans vehicle inspection facilities, and rest areas) were generally similar to each other and lower than highways and toll plazas. This pattern was consistent for the categories of conventional constituents and trace metals with few exceptions, and somewhat less consistent for nutrients. These results for facility types tend to confirm the importance of AADT as a predictor of pollutant concentrations in runoff and as an important factor in prioritizing the implementation of management alternatives.

- There were also significant differences in highway runoff quality for different geographic regions. However, the apparent effects of region may be due more to the actual effects of typical AADT and land use within those regions. Regions with pollutant concentrations that were significantly higher than average (Klamath Mountains, Central Coast, Central Valley, and North Coast and Interior Ranges) were represented by only a few sites with high AADT, or were in primarily urban areas (the Central Coast region is predominantly comprised of San Francisco Bay area sites). Lower than average regions (Sierra Nevada Foothills and Temperate Desert) were represented by only a few sites with low AADT and little urban influence. These results appear to be more supportive of the effects of AADT and urban influence on runoff quality than for consistent region-wide effects of other undefined factors.
- The results of analysis of surrounding land use effects indicated that most conventional pollutants, trace metals, and nutrients were higher in agricultural and commercial areas. Runoff quality from residential areas, transportation corridors, and open land use areas were generally similar to each other and lower than agricultural and commercial areas.

Relevance to Management of Runoff from Department Facilities

It should be noted that the large number of data in the Department's Stormwater Quality Database provides statistical power sufficient to detect relatively small effects on runoff quality (as small as 5% of total variation, as evidenced by the low R^2-values for significant MLR models for some constituents). Taking that into consideration, three results of these analyses have particular relevance to management or treatment of runoff from the Department's facilities:

- ***AADT*** - Pollutant concentrations increase in proportion to the annual average daily traffic for the contributing facility.
- ***Seasonal First Flush Effect and Antecedent Dry Period*** - Concentrations of most pollutants are higher when cumulative seasonal precipitation is lower — i.e., early in the wet season — and pollutant concentrations also tend to increase with longer antecedent dry periods.
- ***Storm Event First Flush Effect*** - This and other studies provide evidence that concentrations of most pollutants are significantly higher in the initial runoff from a storm event.

Value of MLR Models for Prediction and Runoff Management

MLR analysis of the Department's runoff quality data has been able to successfully identify environmental and site-specific factors that significantly effect runoff quality. Knowledge of these factors and their effects on runoff quality should be useful to the Department in evaluating future management alternatives, planning future monitoring efforts, and designing studies of management effectiveness. However, although MLR analyses have been valuable in identifying factors that have the greatest known influence on runoff quality, the MLR models developed for this study are still able to account for much less than 50% of the variability of most constituents in runoff. For this reason, there are significant limitations to the use of the models resulting from these analyses. Although the models developed herein may not be adequately accurate for prediction of concentrations or loads for specific sites and storm events, they can be used to provide improved estimates of long-term average concentrations or loads from Department facilities as a whole.

In a review of the statistical procedures used for this study, staff of the University of California, Davis Statistics Laboratory concluded that some marginal improvements in predictive value of the models would likely be gained and some potential biases moderated by expanding the statistical techniques used, particularly by introducing additional covariate terms. The additional methods recommended for consideration in this review included expanded exploration of transformations of predictor variables, multivariate ANCOVA, and principal components analysis. However, the review also concluded that improvements in the models would be incremental and would not change the overall conclusions drawn based on this study of the data.

Discharge Load Modeling and TMDLs

Developing MLR models for runoff quality has a number of practical applications. Modeling of runoff quality allows more accurate comparisons with relevant water quality regulatory limits than the simple statistical estimates of percent exceedance generated for this study. These models also provide tools relevant to BMP development and assessment and runoff management. Additionally, by combining runoff quality models of EMCs with runoff quantity models, pollutant loads can be better estimated. The relatively low coefficients of determination (R^2-values) for most of the significant MLR model parameters may limit appropriate uses of the MLR models to “big picture” management decisions. However, the current MLR models will still provide estimates of overall runoff quality and loads that are unbiased and with narrower confidence limits than simply using average annual estimates of mean runoff quality and rainfall or runoff.

The ability to estimate pollutant loads from the Department’s highway facilities as accurately as possible may be important in developing TMDLs for specific pollutants (depending on the form of the TMDLs) and subsequently in assessing the ability of the Department to comply with TMDL requirements included in their NPDES permit. If estimating pollutant loads is the ultimate use of MLR models, it may be possible to develop more accurate models of loads (i.e., models with higher R^2-values and lower residual mean squared values) directly from pollutant load data and additional site-specific or environmental independent factors. However, variability of pollutant loads (as measured by coefficient of variation) is typically much higher than for EMCs because storm event runoff volumes and loads typically vary by a couple of orders of magnitude for a specific drainage. The inherently higher variability of loads means models based directly on load data may be no more accurate or predictive than the current models.

Percentage of Metals in the Particulate Fraction

A large proportion of the concentrations of most metals are bound to particulate matter in runoff. Because most management practices and processes for treating stormwater target the particulate portion of runoff, metals with a higher percentages in the particulate fraction are presumed to be more efficiently removed or controlled. Based on data from Statewide discharge characterization studies for the metals with data available for both dissolved and total analyses, lead has the highest proportion present as particulates (86%). Cadmium, chromium, and zinc are between 60-70% in the particulate fraction, and arsenic, copper and nickel are between 50-55% in the particulate fraction. This indicates that at least 50% of these metals may be effectively managed or removed from runoff by targeting the particulate fraction, with the most effective removals expected for lead, cadmium, chromium, and zinc. Table 4-1 summarizes the particulate percentages for the several metals for which both dissolved and total concentration data were available.

Table 4-1 Particulate fraction of metals.

Metal	Percent Present as Particulates (Average for all facilities)
Arsenic	53%
Cadmium	63%
Chromium	68%
Copper	51%
Nickel	54%
Lead	86%
Zinc	69%

Use of Statewide Discharge Characterization Data

Summary statistics for highway runoff data from the three-year Statewide Discharge Characterization Study and from the overall Caltrans monitoring dataset were evaluated for patterns of differences between the two datasets. For these comparisons, the “overall” data set contains data from projects conducted generally before the Statewide Discharge Characterization Study, plus the data from the Statewide Characterization Study, while the “statewide characterization” data set contains only data from the Statewide Characterization Study. Ratios of the means, standard deviations, and coefficients of variation (COV) for highway runoff data were calculated as *Overall statistic ÷ Statewide characterization study statistic*, for core Department monitoring parameters. This analysis was performed to evaluate whether use of the representative Statewide Characterization Study monitoring design was able to moderate a bias of earlier monitoring efforts towards highly urbanized sites. The results of the evaluation are summarized in Table 4-2.

Averaged across monitoring parameters, the means, standard deviations, and COVs were all higher for the overall dataset. Means decreased by about 8% on average for the statewide characterization dataset when compared to the overall data set, with decreases of more than 10% for 27% of parameters, and decreases of 20% or more for 19% of parameters. This pattern indicates that earlier concerns about potential biases due to site selection in the pre-Statewide Characterization Study data set were warranted, and that the more rigorous process of selection of monitoring locations for the Statewide Characterization Study was important in providing a more representative estimate of runoff quality.

The difference in variation for the datasets (as measured by standard deviation and COV) was even more dramatic, with variability of the statewide characterization dataset lower than the overall data set by 10% for approximately 50% of the parameters, and lower than the overall data set by 20% for about 20% of the parameters. This suggests that implementation of more consistent sampling procedures as part of the Statewide Characterization Study was successful in decreasing data variability, even with an increase in the variety and range of sites and geographic regions monitored. The overall pattern of these results highlights the importance of using the Statewide Characterization Study data to characterize the Department's runoff quality and to evaluate the factors affecting stormwater runoff.

Table 4-2 Comparison of highway summary statistics from the Statewide Characterization Study (2000/01-2002/03) and overall dataset (1998/99-2002/03)

Ratios of Summary Statistics for SWCS Data to Overall Dataset

Parameter	Mean	SD	COV
DOC	0.96	0.83	0.86
EC	0.49	0.11	0.22
Hardness as CaCO3	0.81	0.53	0.65
pH	0.99	1.03	1.04
TDS	0.57	0.22	0.39
Temperature	0.99	1.02	1.03
TOC	1.03	0.91	0.89
TSS	0.79	0.65	0.83
As, dissolved	0.91	0.86	0.95
As, total	1.01	1.17	1.16
Cd, dissolved	0.99	1.21	1.22
Cd, total	0.92	1.28	1.40
Cr, dissolved	1.07	0.90	0.84
Cr, total	0.96	0.90	0.94
Cu, dissolved	0.99	0.92	0.92
Cu, total	0.76	0.09	0.12
Ni, dissolved	1.09	0.96	0.88
Ni, total	1.02	0.84	0.82
Pb, dissolved	1.31	1.31	1.01
Pb, total	0.82	0.94	1.16
Zn, dissolved	0.96	0.89	0.92
Zn, total	0.94	0.95	1.01
NO3-N	1.05	1.39	1.33
Ortho-P, dissolved	1.03	1.23	1.19
P, total	0.64	0.29	0.45
TKN	0.93	0.82	0.89
mean ratio	0.92	0.86	0.89
% decreases in statistic	69%	69%	62%
% of decreases > 10%	27%	46%	46%
% of decreases > 20%	19%	23%	19%

Annual Variability in Stormwater Runoff Quality

For highways, annual variation in statewide runoff quality was very low. Other types of facilities saw relatively higher degrees of annual variation.

Overall, annual variation was less than 10% or not significant for 75% of the facilities and parameters (116 of 154 separate comparisons). Notably, the overall trend observed in the results is that facility types with higher numbers of sites and broader geographic representation exhibited lower annual variability. Highways, which are represented by the most sites (46) and have the broadest geographic representation in the data set, exhibit annual variation that is less than 5% of the total variation for most parameters. Maintenance and park-and-ride facilities (with seven and ten sites, respectively) exhibit an intermediate level of annual variation (less than 15% for most parameters). Caltrans vehicle inspection facilities (two sites), rest areas (three sites), and toll plazas (two sites) exhibited the highest annual variation, with statistically significant annual variation in the range of 20-40% for many parameters, and greater than 40% annual variation for DOC and total copper from rest areas.

The most likely reason for this pattern in significant annual variation is that many of the factors expected to cause significant annual variation in runoff quality (e.g., changes in patterns of use, annual variations in weather and deposition patterns, or implementation of management practices) are site-specific or regional factors and would not affect all sites equally. Consequently, runoff quality for facility types represented by few sites is more likely to exhibit significant annual variation. However, based on the results for highways, annual variation for any facility type with broad geographic representation and sufficient numbers of sites is likely to be fairly low on a statewide basis—less than 5% of total variation for most parameters. Conversely, annual variability is expected to be much higher on a site-specific and regional level.

Based on the results for highways, it can be concluded that annual variation will have little impact on the characterization of the Department's average runoff quality *on a statewide basis*. However, annual variation becomes more important for characterization of runoff quality at smaller regional or site-specific scales. The conclusions drawn from these analyses also depend on the assumption that the period monitored is adequately representative of longer-term annual variability —an assumption that is probably not valid for the state as whole.

Comparisons with Water Quality Objectives

The Department's stormwater runoff quality data were compared to statewide water quality objectives found in the California Toxics Rule (CTR) and other surface water quality regulations as a means of identifying constituents with higher priority for future monitoring, or potentially greater need for BMP study and implementation (either structural or source controls). Because these water quality objectives apply to receiving waters, and not directly to runoff, the comparisons are useful as general guidelines for prioritizing pollutants, and do not reflect regulatory compliance status. After comparisons to CTR and other water quality objectives relevant to the discharge of stormwater, constituents were ranked according to their expected frequency of exceedance of the most stringent objective. Priority rankings of *high*, *medium*, and *low* were assigned based on exceedance rates of greater than 50%, 5%-50%, and less than 5%, respectively.

As result of these comparisons, it was determined that copper, lead, and zinc exceeded relevant objectives most frequently and therefore receive a *high* priority for future monitoring, and BMP study or implementation. The comparisons between CTR and other relevant surface water quality objectives and the Department's stormwater runoff quality data are discussed below:

- Based on comparisons with CTR and other relevant water quality objectives, copper, lead, and zinc are assigned high priorities, due to frequent exceedances of surface water quality objectives for both total and dissolved fractions of these metals. Expected frequencies of exceedance for these metals in stormwater runoff is greater than 85% for total fractions and greater than 50% for dissolved fractions of these metals.

- Based on comparisons with CTR and other relevant surface water quality objectives, arsenic, cadmium, chromium, and nickel receive lower priorities. As a group, the total fractions of these metals exceeded objectives in fewer than 25% of stormwater runoff samples, and the dissolved fractions are expected to exceed objectives in fewer than 5% of runoff samples. (Note: It is expected that these parameters would all benefit from the same BMPs as copper, lead, and zinc.)

- Based on comparisons with CTR and other relevant surface water quality objectives, semi-volatile organic compounds merit low priority rankings. In this category, only benzo(b)fluoranthene was observed to exceed any objective, and most constituents were not detected or were well below any relevant objectives.

- Based on comparisons with U.S. EPA drinking water MCLs for TDS, nitrate, and nitrite (the most stringent objectives), these parameters receive low priority rankings. These parameters were estimated to exceed their MCLs in less than 4% of samples. However, nitrate, TKN, total phosphorus, and dissolved orthophosphate are elevated to a higher priority in anticipation of the development of statewide nutrient objectives in the future.

Certain other constituents, such as chlorpyrifos and diazinon, were found at elevated concentrations, but were monitored for few events and at few sites. While these constituents were frequently observed at concentrations above California Department of Fish and Game recommended criteria for diazinon and chlorpyrifos, these criteria have not been officially adopted and do not currently have official regulatory status in California. Furthermore, these pesticides are not routinely used by the Department within highway right-of-ways. For these reasons, these constituents are not designated as high priority parameters for monitoring or management.

Many other parameters monitored by the Department do not have relevant statewide water quality objectives and were therefore not ranked based on comparisons to objectives.

Correlations Between Stormwater Runoff Quality Parameters

The purpose of evaluating correlations between stormwater runoff quality parameters was to determine whether monitoring of some specific parameters could be discontinued or reduced, based on strong correlations with other parameters. Based on the results of these analyses, there were a few cases for which relationships were strong enough to allow reduced monitoring for specific constituents of interest. The majority of these cases were conventional constituents: organic carbon, parameters related to dissolved minerals or dissolved solids (EC, TDS, and chloride), and suspended solids (TSS and turbidity). Additionally, total petroleum hydrocarbons could be adequately monitored by a single fraction in this category (diesel or heavy oil), because other fractions were below detection in the majority of samples. For the purpose of assessing BMP and management effectiveness, it would also be adequate to monitor only a few of the highly correlated metals in the total metals category.

The following priorities are identified for future monitoring and BMP studies based on strong correlations between runoff quality parameters:

- Continue monitoring TOC and discontinue DOC (based on a significant Pearson's correlation of 0.960).
- Continue monitoring TSS and discontinue turbidity (based on a significant Pearson's *R* of 0.784).
- Continue monitoring EC and discontinue chloride and TDS (based on significant Pearson's correlations of 0.970 and 0.805).
- Continue monitoring TPH (Heavy Oil) or TPH (Diesel), but not both (based on a significant Pearson's correlation of 0.858 between these parameters).
- For the purpose of assessing the effectiveness of management alternatives and BMPs in reducing total metals in runoff, only copper, lead, and zinc are high priorities for future monitoring. This is based on a high degree of intercorrelation among total concentrations of these metals with aluminum, cadmium, chromium, iron and nickel, as well as the fact that copper, lead, and zinc warrant a higher priority than other trace metals, based on comparisons with water quality objectives discussed previously.

Prioritization of parameters for future monitoring and BMP studies is summarized in Table 4-3.

Based on comparisons to objectives and evaluation of correlations between parameters, the constituents with high priority for future monitoring and BMP studies are as follows:

- pH
- Temperature
- Conductivity (EC)
- Total Suspended Solids (TSS)
- Total Organic Carbon (TOC)
- Aluminum (total and dissolved)
- Iron (total and dissolved)
- Copper (total and dissolved)
- Lead (total and dissolved)
- Zinc (total and dissolved)

Table 4-3 Summary of priority rankings for future monitoring and BMP studies, based on comparisons with water quality objectives and correlation analyses.

Parameter	Priority (Based on Comparison to Water Quality Objectives)	Comment
Conventional		
Conductivity (EC)	No relevant objective	Surrogate for TDS and chloride
Chloride	MEDIUM	Replace with EC
Hardness as CaCO3	No relevant objective	
pH	No relevant objective	
Temperature	No relevant objective	
Total Dissolved Solids (TDS)	LOW	Replace with EC
Total Suspended Solids (TSS)	No relevant objective	Replace with Turbidity
Turbidity	No relevant objective	Surrogate for TSS
Organic Carbon, Total (TOC)	No relevant objective	Surrogate for DOC
Organic Carbon, Dissolved (DOC)	No relevant objective	Replace with TOC
Metals		
Aluminum	HIGH	Assess effectiveness of BMPs for metals based only on highest priority metals: copper, lead and zinc
Arsenic	LOW	
Cadmium	MEDIUM	
Chromium	LOW	
Copper	HIGH	
Iron	HIGH	
Lead	HIGH	
Nickel	MEDIUM	
Zinc	HIGH	
Nutrients		
Ammonia	LOW	
Nitrate	LOW	
Nitrite	LOW	Infrequently detected (~25%)
Total Kjeldahl Nitrogen	No relevant objective	
Tota Phosphorus	No relevant objective	
Dissolved Orthophosphate	No relevant objective	
Herbicides		
Diuron	No relevant objective	
Glyphosate	No relevant objective	
Oryzalin	No relevant objective	
Oxadiazon	No relevant objective	
Triclopyr	No relevant objective	
Total Petroleum Hydrocarbons		
Oil and Grease	No relevant objective	
TPH (Gasoline)	No relevant objective	Rarely detected
TPH (Heavy Oil)	No relevant objective	Surrogate for TPH (Diesel)
TPH (Diesel)	No relevant objective	Replace with TPH (Heavy Oil)
Semi-Volatile Organic Compounds		
Acenaphthene	LOW	Rarely detected
Acenaphthylene	LOW	Rarely detected
Anthracene	LOW	Rarely detected
Benzo(a)Anthracene	LOW	Rarely detected
Benzo(a)Pyrene	LOW	Rarely detected
Benzo(b)Fluoranthene	LOW	Rarely detected
Benzo(ghi)Perylene	LOW	Rarely detected
Benzo(k)Fluoranthene	LOW	Rarely detected
Chrysene	LOW	Rarely detected
Dibenzo(a,h)Anthracene	LOW	Rarely detected
Fluoranthene	LOW	Rarely detected
Fluorene	LOW	Rarely detected
Indeno(1,2,3-c,d)Pyrene	LOW	Rarely detected
Naphthalene	LOW	Rarely detected
Phenanthrene	LOW	Rarely detected
Pyrene	LOW	Rarely detected

SECTION 5 SUMMARY AND CONCLUSIONS

SUMMARY

The Department conducted comprehensive monitoring of runoff from transportation facilities throughout the State of California during the period 1997-2003. The centerpiece of this effort was the three-year Statewide Characterization Study, conducted from 2000-2003. The Statewide Characterization Study was designed to provide data representative of runoff from the full range of transportation facility types, geographic locations, traffic levels, and land use characteristics for facilities under the Department's purview.

The monitoring was conducted using consistent protocols designed to ensure the scientific validity of the data. Several significant innovations were developed to assist the Department's staff and contractors in assuring quality control and consistency in monitoring and data management.

The Department's extensive monitoring has provided sufficient data with which to characterize the quality of runoff from the "edge of pavement" from the Department's highway facilities. This goal also has been achieved, though less intensively, for other types of transportation facilities that have been monitored by the Department. Based on these results, continued extensive monitoring of the type and scale performed under the Statewide Characterization Study is not necessary, as this study has provided sufficient information about the characteristics of edge-of-pavement runoff quality and its variability.

Factors Affecting Runoff Quality

Environmental factors affecting the quality of edge-of-pavement runoff have been identified and quantified in this report, and the major patterns of temporal variability (annual, seasonal, and intra-storm) have been evaluated. Analysis of the Statewide Characterization Study monitoring data has confirmed that AADT and storm event characteristics have statistically-significant effects on runoff quality from transportation facilities. Consideration of these factors can be included in planning and prioritizing efforts for future monitoring and for management of runoff quality from such facilities.

AADT is the most important site characteristic affecting runoff quality of those identified to date for highways. Precipitation characteristics, particularly antecedent dry period, cumulative seasonal rainfall, and event rainfall amount, are also statistically-significant factors affecting the quality of runoff from highways.

However, because the correlation coefficients were generally low ($R^2 < 0.5$), it is also clear that there are other unaccounted-for factors contributing to variability in runoff. These factors may include aerial deposition under both wet and dry conditions.

Although geographic region and contributing land use were determined to have some statistically-significant effects on runoff quality, these effects use are less consistent than AADT and the precipitation factors. Consequently, geographic region and land use characteristics are less valuable in predicting runoff quality and should be considered less important in planning and prioritizing stormwater monitoring and management activities. The results of this analysis may be applied to other transportation facility types within California.

Other factors that have not received such intensive attention may influence runoff quality from transportation facilities. Predominant among these are the effects of runoff from additional surfaces beyond the paved surfaces, within the transportation corridor right-of-way.

CONCLUSIONS

The following are the principal conclusions derived from this study:

- Transportation facilities with higher traffic levels (i.e., higher AADT), particularly highways and toll plazas, produce higher pollutant concentrations in runoff than lower AADT sites and other types of facilities.
- Concentrations of most pollutants are higher early in the wet season and after extended dry periods. These results support the idea that there is a build-up of pollutants during dry periods, with progressive wash-off during the rainy season, leading to what is commonly known as the seasonal “first flush effect.”
- Runoff pollutant concentrations decrease as storm size increases; smaller storms produce higher pollutant concentrations in runoff than those with larger rainfall amounts.
- The majority of the metals present in runoff are found in the particulate form.

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